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A STUDY OF LANDING GEAR REBOUND AND SUBSEQUENT RUNOUT CHARACTERISTICS

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FAIRCHILD ENGINE AND AIRPLANE CORPORATION

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AIRCRAFT LABORATORY
CONTRACT No. AF 33(616)-394
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WRIGHT AIR DEVELOPMENT CENTER
AIR RESEARCH AND DEVELOPMENT COMMAND
UNITED STATES AIR FORCE
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

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FOREWORD

The experimental and analytical studies presented in this report are the results of a contract initiated by the Structures Branch of the Aircraft Laboratory of the Wright Air Development Center under Contract No. AF 33(616)-394 with the Fairchild Aircraft Division of the Fairchild Engine and Airplane Corporation. The data shown herein represent a partial completion of an original proposal to completely investigate the rebound and runout characteristics of airplanes having all conceivable types of landing gear configurations. Tests conducted specifically for this contract were made only on one airplane, namely, the Fairchild Model C-119-H. However, some data have been included for other airplanes, most of which were supplied by the Aircraft Laboratory of the Wright Air Development Center. The other airplanes included are the C-119-G, C-47, B-36, and F-84. Although no test data are included, calculations are shown for the XC-120 quadricycle landing gear. The landing tests were conducted at the Fairchild Aircraft Division plant at Hagerstown, Maryland.

The numerical calculations which provide statistical data for the report were made on the IBM Card-Programmed Electronic Calculator.

Landing test records for the C-47, F-84, B-36 airplanes were supplied by the Aircraft Laboratory of the Wright Air Development Center. The contract was initiated to establish a basis for improvement of the landing gear design criteria. The project was sponsored by Mr. G. M. Goldman, Chief of Design Criteria Section, WCLSS, with the technical assistance of Mr. E. J. Lunney, Chief of Dynamic Loads Section, WCLSY.

This report was prepared on Air Force Contract AF 33(616)-394 under Project Number 1367, Task 13583.

ABSTRACT

This report presents results of an analytical and experimental study of the landing gear rebound problem. It includes results of an experimental investigation of the landing characteristics of the Fairchild Model C-119-H Airplane together with some data for other airplanes supplied by Wright Air Development Center. An analytical investigation of quadricycle and tricycle landing gears was made and the results correlated with data from landing tests. Methods are shown for taking into consideration any geometrical arrangement of the landing gear units. The analytical treatment was simplified considerably by introduction of the notion of effective mass; it is shown that this notion can be used to facilitate correlation of the analytical results with drop test data. A comparison of the results obtained with results of impulse-momentum methods is shown. The effect of changing certain of the parameters such as geometry, inertia, and external forces is considered. It was found that the second impact is usually somewhat more severe than the first. The problem of formulating adequate design criteria for landing gears is discussed. A review of literature pertinent to the problem is presented.

PUBLICATION REVIEW

This report has been reviewed and is approved.

FOR THE COMMANDER:

for E H Schwartz

D. D. McKee
Colonel, USAF
Chief, Aircraft Laboratory
Directorate of Laboratories

TABLES

FIGURES

FIGURES (cont'd)

FIGURES (cont'd)

NOMENCLATURE

1.	W	Weight of Airplane (pounds)
2.	L	Total Aerodynamic Lift on Airplane (pounds)
3.	M	Mass of Airplane (pounds sec.^{2}/in.)
4.	I_{xx}	Moment of Inertia about x-axis (pound-inches-sec.^{2})
5.	I_{yy}	Moment of Inertia about y-axis (pound-inches-sec.^{2})
6.	I_{zz}	Moment of Inertia about z-axis (pounds-inches-sec.^{2})
7.	$M_{i\ eq.}$	Equivalent Mass for i^{th} Landing Gear Unit (pounds)
8.	x	Fore and Aft Coordinate (inches) Positive Forward
9.	y	Lateral Coordinate (inches) Positive to Right
10.	z	Vertical Coordinate (inches) Positive Down
11.	φ	Roll (radians) Positive Right Wing Down
12.	θ	Pitch (radians) Positive Nose Down
13.	ψ	Yaw (radians)
14.	$\bar{z}_i$	Vertical Displacement of i^{th} Landing Gear Unit (inches)
15.	l_i	Lateral Moment Arm to Airplane c.g. for i^{th} Landing Gear Unit (inches)
16.	r_i	Fore and Aft Moment Arm to Airplane c.g. (inches)
17.	h_i	Vertical Moment Arm to Airplane c.g. for i^{th} Landing Gear Unit (inches)
18.	V_i	Vertical Component of Force on i^{th} Landing Gear Unit (pounds)
19.	D_i	Fore and Aft Components of Force on i^{th} Landing Gear Unit (pounds)
20.	S_i	Lateral Component of Force on i^{th} Landing Gear Unit (pounds)
21.	K_i	Equivalent Spring Rate for i^{th} Landing Gear Unit
22.	C_i	Coefficient of Viscous Damping for i^{th} Landing Gear Unit

23.	C_{φ}	Coefficient of Aerodynamic Damping for φ Motion
24.	C_{θ}	Coefficient of Aerodynamic Damping for θ Motion
25.	C_{ψ}	Coefficient of Aerodynamic Damping for ψ Motion
26.	μ_s	Coefficient of Friction for Side Force
27.	μ_d	Coefficient of Friction for Drag Force
28.	L_i	Coefficient of (W - L) depending upon Geometry, Inertia, and Side Force
29.	T	Total Kinetic Energy of the Airplane
30.	t	Time-(Seconds)
31.	t_m	Time at which Maximum Force Occurs

INTRODUCTION

Experimental data and analyses of the data relevant to the problem of formulating criteria for the design of aircraft landing gears are presented in this report.

In this study the airplane has been considered as a rigid body. From the point of view of landing gear design, this assumption is conservative, since it neglects dissipation of landing gear forces through the excitation of vibrations of the elastic structure. From the point of view of over-all aircraft design, it would be necessary, of course, to take account of the various flexible modes of vibration of the structure, in order to determine the maximum stresses that might be developed in any of its members due to the landing impact.

The airplane for which new experimental data were obtained in this study and are presented in this report is the C-119-H.

An actual dynamical system is usually too complicated for mathematical treatment. For such treatment it is thus necessary to describe a simplified equivalent system. This is true of a landing gear system. Such a system presents nonlinearities in its response characteristics due to frictional damping, polytropic compression of air, and the flow of oil through an orifice. In the present study the problem was linearized through the use of an equivalent spring rate calculated from drop test data. However, provision has been made for treating the nonlinear case.

The equivalent system used in the present study is described in this report. Equations of motion for the equivalent system were written and solved analytically. Numerical values of the solutions were calculated with the help of the card-programmed electronic calculating machine. A check on the adequacy of the equivalent system, as well as the accuracy of the calculations, is provided by charts showing a comparison of calculated with test results. The agreement shown in this report is considered satisfactory.

A novel feature of the present treatment is the use of the notion of effective mass. As used in this report, the notion of effective mass is associated with a single degree of freedom. Through the use of the notion of effective mass it was found possible to correlate results of drop tests with the dynamics of the airplane.

This report presents a survey of literature on landing gear research designed to supplement, and bring up to date, the rather extensive survey presented in Reference 13. The list of references is by no means complete; it represents literature actually referred to in the report.

SURVEY OF LITERATURE

Landing-gear research apparently had its origin in Germany before the last war (Ref. 4) This early landing-gear research was influenced by official regulations. These regulations required that a drop test be made in which the upper end of the shock strut was attached to a weight and dropped on an anvil. At the instant when the anvil was struck the weight was compensated by admitting compressed air to a cylinder. The load-stroke curve obtained by this method was considered as <u>the</u> load-stroke curve of the shock strut and was used in the design of the airplane. Consequently this early research was directed toward the investigation of load-stroke diagrams.

The only papers on landing-gear research that appeared in Germany before the war were by Michael (Ref. 10), published in 1937, and by Frank and Kranz (Ref. 5), published in 1939. The first of these papers gives an analysis of the linear spring-damper system but pays little attention to the tire. Spring diagrams are used in which force is plotted against stroke with rate of stroke as a parameter. These diagrams are also shown for shock struts with dry friction or with velocity-square dampers, and are used for graphical solution of the differential equations. Such diagrams are not useful when a second spring, the tire, is considered; therefore, their use has been abandoned.

The second of the early papers, (Ref. 5), discusses such questions as length of runway necessary for takeoff and influence of tire pressure on landing gear reaction. The oleo is not mentioned in this report, however. Simulated runout tests of landing gears were made by attaching the gear to be tested to a specially designed frame which was hitched as a trailer to a truck provided with recording instruments.

The first papers of the war period were focused on the load-stroke diagram. Schlaefke (Ref. 14) in 1943, criticized the drop test method in use at the time and suggested replacing the buffered drop test by an unbuffered test, that is, omitting the air cylinder. This paper uses the theory of the linear spring-damper system to establish some relations between the results of both types of tests.

In the next group of papers the tire was considered. Kochanowsky (Ref. 8) in 1944, gave an analysis of an oleo-tire combination. He considered the unsprung mass to be negligible for the landing impact.

After studying thelinear oleo-tire system, the next logical step would have been to consider a non-linear system. Such a study was made by Kochanowsky for a type of non-linear spring which had long been used in railroad car bumpers, a ring-pile type of spring.

The other paper which considers a non-linear shock strut is by Marquard and Meyer zur Capellen in 1943 (Ref. 9). This paper considers velocity square damping and polytropic compression of air.

A discussion of "Dynamic Loads on Airplane Structures During Landing" is presented by Biot and Bisplinghoff, (Ref. 2). This report undertakes to apply transient theory to the determination of dynamic loads on airplane structures during landing impact. It presents a brief outline of the mathematical theory of transients in undamped elastic systems using the real convolution integral superposition method. Structural flexibility is considered in determining the transient oscillations excited by the initial landing impact. It is indicated that under certain conditions regarding the airplane as a rigid body may fail to be a conservative assumption.

It is assumed that the time history of the impact force may be studied independently of the elastic properties of the structure. Since the designer is not so much interested in the time histories of the forces acting on the structure as he is in the highest attainable stresses during the operation of the airplane, the envelope of the various impact force curves is used to determine the maximum stress. This envelope represents conditions which exceed in severity every type of landing considered. This method may be used to calculate design landing dynamic response factors for the airplane. By this means the maximum deflection of the structure in each mode during the landing may be evaluated. Loss of phase relationship by this method is not considered serious since for design purposes it must be assumed that sometime during the life of the airplane the phasing between the modes will be such as to produce the worst combination of stresses.

It is considered possible that a resonance condition during the run-out phase of the landing may produce stresses more critical than those produced during and shortly after the initial impact. Aerodynamic damping, as well as coupling between the motion of the structure and the external force, is neglected.

Reference 17 presents an analytical solution to the problem of determining the transient response of a second-order linear system to a trapezoidal forcing function. Graphs of the forcing function, the displacement function, and the acceleration function, are presented.

Reference 6 presents a method for calculating the dynamic landing response of an elastic airframe from a knowledge of the mass and stiffness distribution of the structure.

A criterion is advanced for determining which vibration modes of the airframe must be taken into account in the landing impact analysis. A method is presented for calculating the response in each normal mode due to landing impact, with effects of damping neglected. It is shown that the effects of both structural and aerodynamic damping can be taken into account by applying a simple correction to the undamped responses.

Extensive landing tests were conducted by the AMC on the B-24 and P-61 airplanes and a comparison is made of the measured and calculated dynamic loads. Generally acceptable correlation is observed, although significant discrepancies are present in certain instances. Trapezoidal, vertical, and drag load time histories are given and accelerometer data are presented in a number of charts.

Reference 13 includes an extensive bibliography and a historical sketch of landing gear research.

Previous research has been directed mainly to the study of structural design criteria for rigid airplanes. Structural design criteria have been drawn up so that an airplane, when constructed in accordance with the criteria, will not have failures in any of its components during its lifetime of normal operation.

A structural failure occurs when the stress at some point in the structure exceeds the stress the material at that point is able to withstand. Such stresses are called ultimate stresses. Structures built in conformity with satisfactory criteria will not develop ultimate stresses under normal conditions. The criteria specified that certain static loads be applied to the airplane and that the structure be designed to withstand these static loads and the associated inertia forces. The criteria were generally satisfactory because of the fact that airplanes of the past were usually relatively rigid and had the same general type of configurations. In certain cases where airplanes had relatively flexible components, failures occurred. Consequently, cognizance has been taken of the fact that the existing criteria are not satisfactory for some of the present day airplanes, and that there is no reason to expect them to be adequate for the airplanes of the future.

Airplanes with increasingly unconventional configurations and increasingly flexible structures, if designed in accordance with present day criteria, may be expected to suffer failures if they are used to perform those functions upon which the present criteria are based. This is because experience has indicated that failures are much more liable to occur for flexible airplanes.

The criteria may be revised by specifying greater static loads for which the structure must be designed, or the criteria may be revised in such a manner that more rational stress analyses must be performed. It remains to set down new criteria such that the dynamic or vibratory stresses associated with flexibility will be accounted for in such a manner that ultimate stresses do not occur.

Ground loads structural criteria are drawn up so that an airplane, when constructed in accordance with these criteria, will not have, at any point in the structure, stresses exceeding the ultimate stress of the material at that point, as a result of ground loads. For the ground loads problem, airplane flexibility may have the effect of either amplifying or attenuating the magnitude of the stresses which would occur in the airplane if it were rigid. Consequently, it is important to determine whether or not flexibility is significant for some particular phase of the problem.

Consider an airplane landing with a given attitude and at a given sinking speed. If the airplane is rigid, the shock strut must transform into potential energy, and dissipate as heat, all the kinetic energy resulting from the vertical component of the velocity. In doing this, a certain magnitude of strut force will be developed. If, on the other hand, the

airplane is flexible, some of the kinetic energy is transformed into elastic potential energy by deflection of the structure, leaving a smaller amount of kinetic energy to be absorbed or transformed by the strut. As a result, the strut force will be smaller than if the airplane were rigid.

In order to permit an evaluation of the reduced-mass method of representing wing-lift in free-fall drop tests of landing gears, the results of such tests have been compared with data obtained in simulated air-borne impacts and in free-fall drop tests with full dropping weight (Ref. 16). These comparisons indicate that:

1. Landing-gear load factors determined from the reduced-mass drop tests were in fairly good agreement with data obtained in the simulated air-borne impacts through most of the vertical-velocity range. At the higher velocities, however, the reduced-mass drop tests yielded load factors up to 12% higher than those in the simulated air-borne impacts. This discrepancy increased to as much as 18% following the occurrence of tire bottoming.

2. Throughout most of the velocity range, the free-fall drop tests with the full weight resulted in load factors which were greater than those obtained in the simulated air-borne impacts by an amount approximately equal to the lift factor.

3. The time required for the maximum load to be attained was somewhat smaller in the reduced-mass drop tests than in the simulated air-borne impacts. The free-fall drop tests with the full weight required a greater time for the attainment of the maximum load than did either of the other two types of tests.

4. The shock-strut effectiveness in the reduced-mass drop tests was considerably lower than in the simulated air-borne impacts, particularly at the lower vertical velocities where differences in strut effectiveness as great as 22% were found. However, these differences decreased to 10% or less at the higher velocities. The effectiveness in the free-fall drop tests with the full weight, however, was approximately 5% greater than in the simulated air-borne impacts and more closely approximated the results of the simulated air-borne impacts than did the reduced-mass drop tests.

Results obtained indicate that the reduced-mass method of drop testing landing gears, although yielding somewhat conservative results, in general more closely approximates the results of air-borne impacts and is an appreciable improvement over the former very conservative practice of using the full weight in the free-fall drop tests. However, when a more exact representation of the time history of the landing gear behavior

is required, as in tests in which drag loads are simulated by the method of wheel spin-up or in tests which are used as a basis for dynamic analyses of flexible structures, it may be necessary to simulate wing-lift by mechanical means rather than by the reduced-mass method of free-fall drop testing.

Studies have been made to determine the importance of the type of the air-compression process on the loads produced on the oleo-pneumatic landing gear during impact and to determine the type of air-compression process actually obtained during drop tests (Ref. 15). The data were obtained in tests of a small landing gear with dropping weights ranging from 1500 to 2500 pounds. Vertical contact velocities ranging from 0 to 11 feet per second were obtained. A simplified analysis to determine the effect which different air-compression processes might have indicates that the value of the air-compression exponent should have little effect on the landing-gear loads throughout most of the impact.

Near the end of the impact, however, differences in the air-compression process may have some effect on the total load, the effect depending on the extent to which increases in the polytropic exponent cause reductions in maximum strut stroke. Analysis of data showed that the polytropic exponent ranged from 1.01 to 1.10 with an average value of 1.06.

Reference 3 presents a number of time histories of strut stroke, tire deflection, and accelerometer readings based on drop test data. From this information, typical forcing functions may be obtained and from a combination of a number of these functions, an envelope forcing function might be obtained, for use in accordance with the method of Biot and Bisplinghoff (Ref. 2).

The following quotations are from reference 1.

> "The airplane, immediately prior to contact with the ground, may have translational velocities and accelerations along the three mutually perpendicular axes. The gear loads result from the reduction of these vectors to zero. The specified landing impact attitudes, velocities, etc., are intended to define the initial contact condition. The subsequent motion of the airplane resulting from this contact shall also be considered.
>
> Lift at contact may be assumed equal to or less than the airplane weight and disposed symmetrically about the plane of symmetry of the airplane. The resultant of the distributed aerodynamic lift may be assumed to pass through the center of gravity of the airplane. In the structural analysis, the aerodynamic lift shall be appropriately distributed to the major components (including the empennage) in accordance with the above assumptions. In general, the magnitude and distribution of the airplane lift may be assumed unchanged by motions subsequent to initial contact."

Criteria for angles of roll, sideslip, and pitch are also presented.

According to Reference 12, the landing gear and the airplane structure are to be investigated for landing conditions at both landing and take-off weights. Maximum spin-up and spring-back loads are the criteria advocated in this report. Design ultimate loads are to be calculated by multiplying these maximum loads by a safety factor of 1.5. In case of multiple wheels, the most severe loads resulting from the various load distributions are to be used in the design of the structure.

This publication recognizes that loads produced by landing impact may be more severe for an elastic structure than those calculated on the assumption that the structure is rigid. The methods of AFTR 5815, Reference 6, may be used in calculating such dynamic loads. It is also stated that where the natural frequency of the landing gear in a fore and aft direction is close to the natural frequency of a major structural component, that condition should be given special investigation.

W. Flugge, in 1952 (Ref. 4), represented the shock strut by a spring and a damper in parallel; the tire is represented by a simple spring whose deformation is proportional to the applied force. Differential equations of such a fourth-order landing gear system are written. The solution of these equations is carried out by elementary text-book methods; it could be simplified by use of the Laplace transformation.

These equations were reduced to third-order by the assumption that the unsprung mass is zero. The effect on the system of not neglecting the unsprung mass was considered. The solutions were obtained in trigonometric and exponential form. The effect on the system of neglecting damping was also considered. The result is not realistic for a system whose principal function is damping.

The spring terms in the linear differential equations correspond to the action of steel springs. Modern shock struts use air as an elastic medium and air does not exhibit linearity. However, the non-linearity introduced by a pneumatic spring is not severe, even in the case of adiabatic compression.

Quite different is the damping term. Viscous damping is never realized in shock struts, their damping being produced by the acceleration of oil squeezed through small orifices.

It was assumed that the tire force follows a linear law and that the shock strut force depends non-linearly on the stroke and the rate of stroke. Numerical methods were used to obtain an approximate solution.

SECTION I DYNAMICS OF THE AIRPLANE

Discussion of the Problem

The total problem of the dynamical behavior of the airplane and all of its component parts during a landing maneuver is one of such magnitude that it defies a practical solution. In order to obtain landing gear design information, it is necessary to separate the problem into several sub-groups of problems, each of which can be solved temporarily by neglecting the effect of other sub-groups. The relationship or effect of each sub-group upon its neighbor is then obtained by statistical methods.

A logical sub-group division of the landing problem is as follows:

a. Rigid body motion of the airplane.
b. Response of the airplane flexibility modes.
c. Nonlinear dynamics of the equivalent drop test configuration involving the oleo and tire characteristics.
d. Spin-up and spring-back response characteristics.
e. The effect of superimposed forces and moments due to control surface manipulation or power steering immediately prior to and during the landing maneuver.
f. Stability of each landing gear unit from shimmy.
g. Superimposed forcing functions such as striking an obstacle or, of lesser importance, power plant oscillations.

In this report the first sub-group analyzed is that of the rigid body motions of the airplane. As can be readily seen, the problem is one of six degrees of freedom, consisting of translation in three mutually perpendicular directions and rotation about the three principal axes. As a first step in the analysis, it is assumed here that the fore and aft, yawing, and lateral motions can be neglected as a first approximation. This leaves three degrees of freedom in the problem namely, vertical translation, roll, and pitch. Equations of motion for these three degrees of freedom are derived in this report.

Analytical solutions have been derived for these three coordinates for numerical solutions of the differential equations on the IBM Card-Programmed Electronic Calculator. Provision was made for introducing the forcing function for nonlinear characteristics in terms of vertical force vs. the total mass travel at each landing gear unit. This was done in order to provide a means for getting the forcing functions by statistical analysis of drop test and landing test data. However, this process was not defined to the point where certain intangible factors could be excluded from the forcing functions so obtained. Hence, the numerical solutions

were confined in this report primarily to the case involving linear springs and viscous dampers. Considerable numerical data are shown on this basis. The effect of several parameters is shown in various charts and tables in this report. It is noted that the analytical work is still very complicated even after the foregoing assumptions have been made. For example, it is necessary to distinguish the cases of 1, 2, or 3 landing gear units in contact with the runway at the same time. In this report, the work was concentrated on the case where each landing gear unit impacted the runway while all others remained clear. It is considered that this constitutes the case where maximum load factors will be developed. However, all cases must be considered when making an elaborate comparison with actual landing test data. This is due to the fact that landing tests are usually made with load factors much lower than required for design criteria. Also, it is difficult for a pilot to obtain a pre-determined set of initial conditions at the instant of contact with the runway. However, the basis for an analytical solution to the problem has been established when it can be shown that the equivalent system exhibits a response in reasonable agreement with that of the airplane. Several comparison graphs are shown in this report to illustrate the closeness with which the airplane is being represented.

For developing design criteria for landing gears, it is advantageous to obtain relationships between the airplane and simulated drop tests. This is the only means by which the concept of true effective mass can be introduced into the problem. Derivations are shown in this report for the three degree of freedom system being considered by means of which to relate the airplane and drop test equations with certain limitations. These derivations are obtained by making a linear transformation from the vertical translation, roll and pitch coordinates to a set of linear coordinates defining the vertical motion of the airplane at each of three landing gear units. However, any number of landing gear units can be studied by means of these equations.

Convenient forms of equations shown in this report were obtained by a coordinate transformation eliminating the inertial and elastic coupling between the coordinates. It is to be noted that this transformation can be effected without neglecting any of the rigid body motions. However, a corresponding number of vertical displacement coordinates must be used. Now if the problem is limited to the case where only one landing gear is in contact with the runway at any instant, a direct relationship can be obtained between the airplane equations and those of the drop test. This is accomplished because the equation associated with the particular landing gear in contact with the runway contains only one coordinate and is entirely independent of the other equations. Hence, the mass term associated with this equation is the true effective mass acting on that landing gear unit. Also, it is possible to adjust the wing-lift in such a manner that complete agreement with the drop test is obtained. For this agreement to be efficient, it is necessary that the term containing $(W - L)$ must equal the dropped weight.

It is noted that the de-coupled equations do not compromise the ability to study the effects of nonlinear landing gear forces. Although considerable work has been accomplished in this report on the basis of linearized forces, it is recommended that future reference be directed along the lines of study based upon statistical representation of a nonlinear landing gear force. Since this has been accomplished for the drop test problem, the identical methods can be employed here. For example, the effect of nonlinear tire forces, and forces due to compressed air and oil flow through the orifice can be introduced directly into the equation for the landing gear in contact with the runway. Of course, this results in a problem for which a numerical solution is required. However, the advantages for obtaining the optimum landing gear design can not be over estimated.

Another advantage of the equations in this form is that the motion in the other coordinates can be determined from the solution of the first equation. For example, once the forcing function for the landing gear in contact with the runway is established, it can be introduced into the other equations to obtain the solution for all coordinates. However, it is noted that the mass terms associated with all landing gear units not in contact with the runway do not have the physical significance of an effective mass. In other words, the mass term associated with any landing gear unit becomes an effective mass only after that landing gear unit contacts the runway.

It is significant to note that putting the derived equations in this form illustrates the importance of the linear vertical velocity at each landing gear unit. All other things being equal, the landing load factor will depend then upon the vertical rate of descent, effective mass, and percentage of wing-lift present. The effect of the wing-lift term can be disregarded in this discussion since it is magnified by a ratio directly related to the effective mass. Hence, the magnitude of the load factor developed on any one landing gear unit will depend primarily upon the vertical rate of descent at that landing gear unit and its effective mass. From the standpoint of landing gear design criteria, this effective mass term represents the main contribution of this report since it includes the effective airplane geometry, external forces such as side loads, and the mass characteristics of the whole airplane. In other words, having established the velocity criteria for the most severe impact, the design landing gear load factor will depend entirely upon the effective mass.

The dynamical motions of an airplane during landing are produced by forces arising from several different sources. Of principal concern are the following.

1. Forces arising from movement of the control surfaces.
2. Engine forward thrust or reverse pitch.
3. Drag due to flap setting.
4. Reactions from landing gear units.
5. Forces due to the dynamic response of the airplane resonant modes.

Other forces which are peculiar to the airplane design or contribute to the difficulty of analyzing test data are

a. Forces arising from a drag parachute or arresting hook.
b. JATO thrust or auxiliary power plants.
c. Drag and lift due to spoilers.
d. Forces due to boundary layer control, etc.
e. Forces due to gusts, ground effects, etc.
f. Unbalance forces in moving parts such as engine, propeller, and landing gear.
g. Aerodynamic impulse from the propeller or slipstream.
h. Aerodynamic impulses from the wake of the wing or fuselage.

The forces due to the control surfaces and power plants at any instant are subject entirely to the pilot's control technique. Since, it is impractical to attempt to write out complete equations to include all possible forces that can act on the airplane, it is customary to assume certain equilibrium conditions at the outset to eliminate some of the forces from the equations. Of course, these assumptions must be consistant with accepted general practice used in landing techniques. However, an attempt is made in this study to search out any combinations of the forces and initial conditions that lead to more severe subsequent impacts.

In regard to the control surfaces, it is assumed that no accelerations are being imposed upon the airplane. In other words, prior to contact, all forces and moments except wing lift are balanced by the control surface settings. Provisions are made for varying the percentage of wing lift effective. The term wing lift is applied to that component of the wing lift perpendicular to the ground. Since it is assumed that the pitching moment acting on the airplane is balanced by the elevator, this component of the wing lift is applied at the airplane center of gravity. This leaves the aerodynamic drag forces which are assumed to be balanced by the forward thrust of the propellers. Hence, it can be seen that the dynamical action of the airplane during landing depends largely upon the initial conditions established at the instant of contact.

Based upon thses assumptions the significant forces acting on a typical airplane are shown in Figure 1.

All of the forces acting to produce motion of the equivalent airplane system are shown in Figure 1. Since the magnitude of the effect of the aerodynamic damping moments are not known, they are included in the equations for investigation. The effect of damping on the translational degrees of freedom is assumed to be negligible. Hence, the equations of motion can be written.

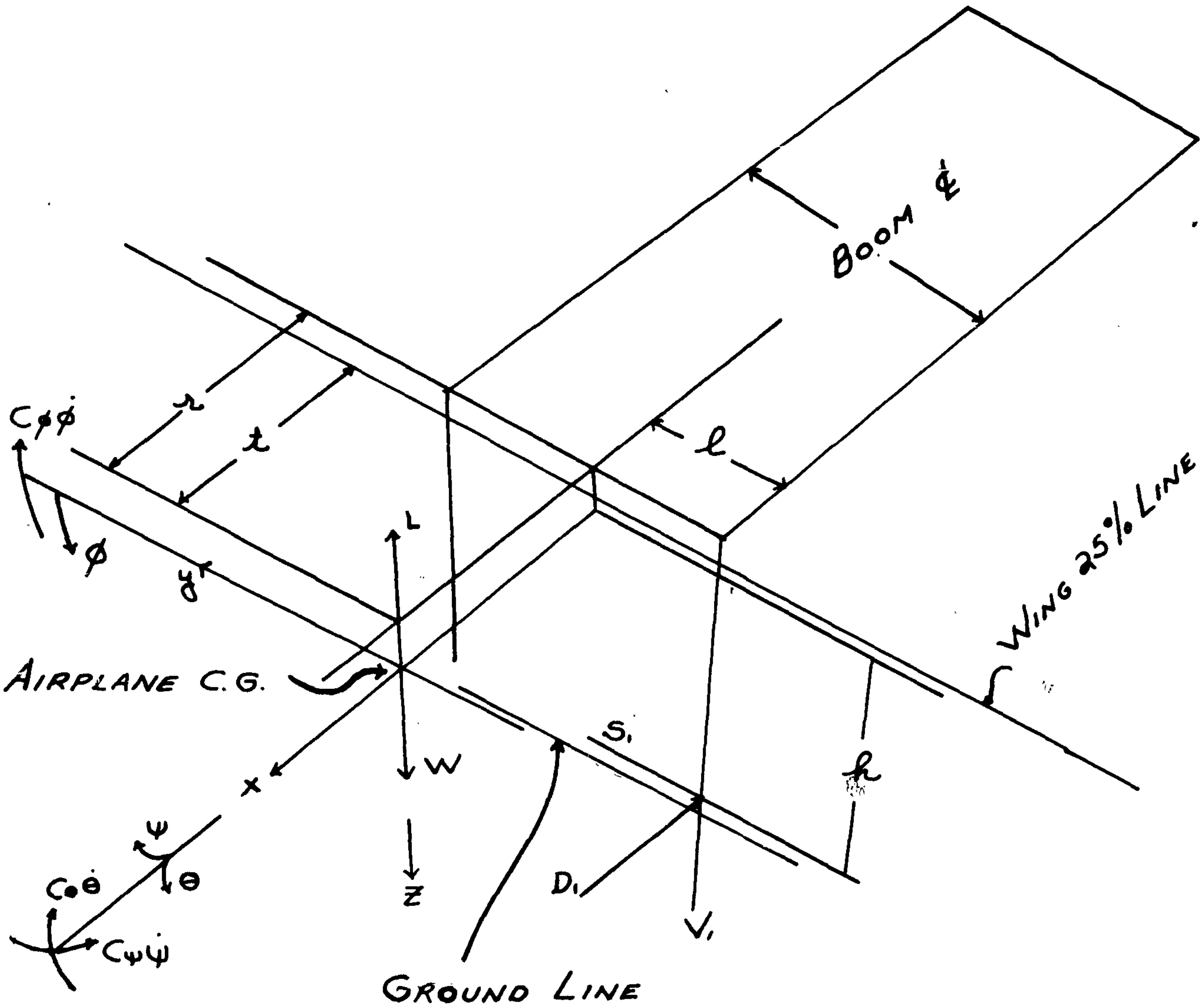


Fig. 1. Geometrical configuration of the airplane during contact of a single landing gear in an unsymmetrical landing maneuver.

$$M\ddot{x} = -D_1$$
$$M\ddot{y} = -S_1 \qquad (1)$$
$$M\ddot{z} = -V_1 + W - L$$
$$I_{xx}\ddot{\phi} = l\,V_1 + h\,S_1 - C_\varphi\,\dot{\varphi}$$
$$I_{yy}\ddot{\theta} = r\,V_1 + h\,D_1 - C_\theta\,\dot{\theta}$$
$$I_{zz}\ddot{\psi} = r\,S_1 - l\,D_1 - C_\psi\,\dot{\psi}$$

Eqs. (1) define the motion of the airplane during the interval of time between initial contact of the first and second landing gear units. Due to the nature of the relatively small displacements of the airplane it has been assumed that the dimensional relationships of the system are adequately defined by an airplane coordinate system always moving parallel to the ground. All of the dimensions will be assumed constant with the exception of h which, of course, varies with the oleo deflection.

The external forces producing motion of the airplane during the interval of time of contact of two landing gear units are shown in Figure 2. The equations of motion become

$$M\ddot{x} = -D_1 - D_2$$
$$M\ddot{y} = -S_1 - S_2 \qquad (2)$$
$$M\ddot{z} = -V_1 - V_2 + W - L$$
$$I_{xx}\ddot{\varphi} = l\,(V_1 - V_2) + h_1\,S_1 + h_2\,S_2 - C_\varphi\,\dot{\varphi}$$
$$I_{xx}\ddot{\theta} = r\,(V_1 + V_2) + h_1\,D_1 + h_2\,D_2 - C_\theta\,\dot{\theta}$$
$$I_{zz}\ddot{\psi} = r\,(S_1 + S_2) + l\,(D_2 - D_1) - C_\psi\,\ddot{\psi}$$

It is noted that Eqs. (2) can be transformed to be identical with Eqs. (1) by setting $V_2 = D_2 = S_2 = 0$. Hence it is concluded that the proper form of the general equations for this study should include the forces acting on all landing gear units. The proper sequence of impacts in any detailed study being obtained by setting all forces not acting equal to zero.

The external forces acting on a tricycle type airplane during any phase of the landing maneuver are shown in Figure 3. The equations are written to include all of the forces shown. Prior to contact or after rebounding clear, the proper equations are obtained by setting equal to zero the forces associated with all the

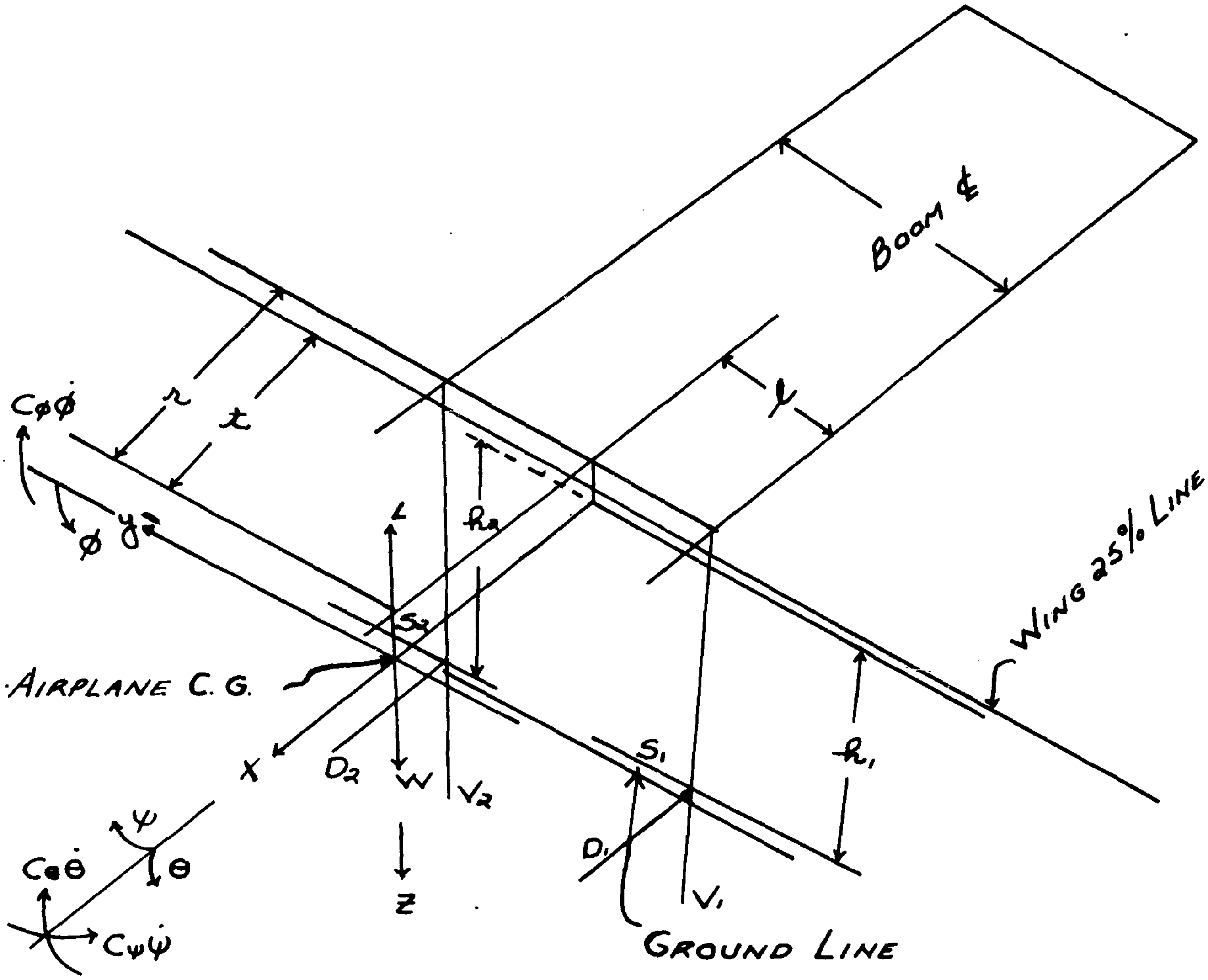


Fig. 2. Geometrical configuration of the airplane during contact of two landing gear units in an unsymmetrical landing maneuver.

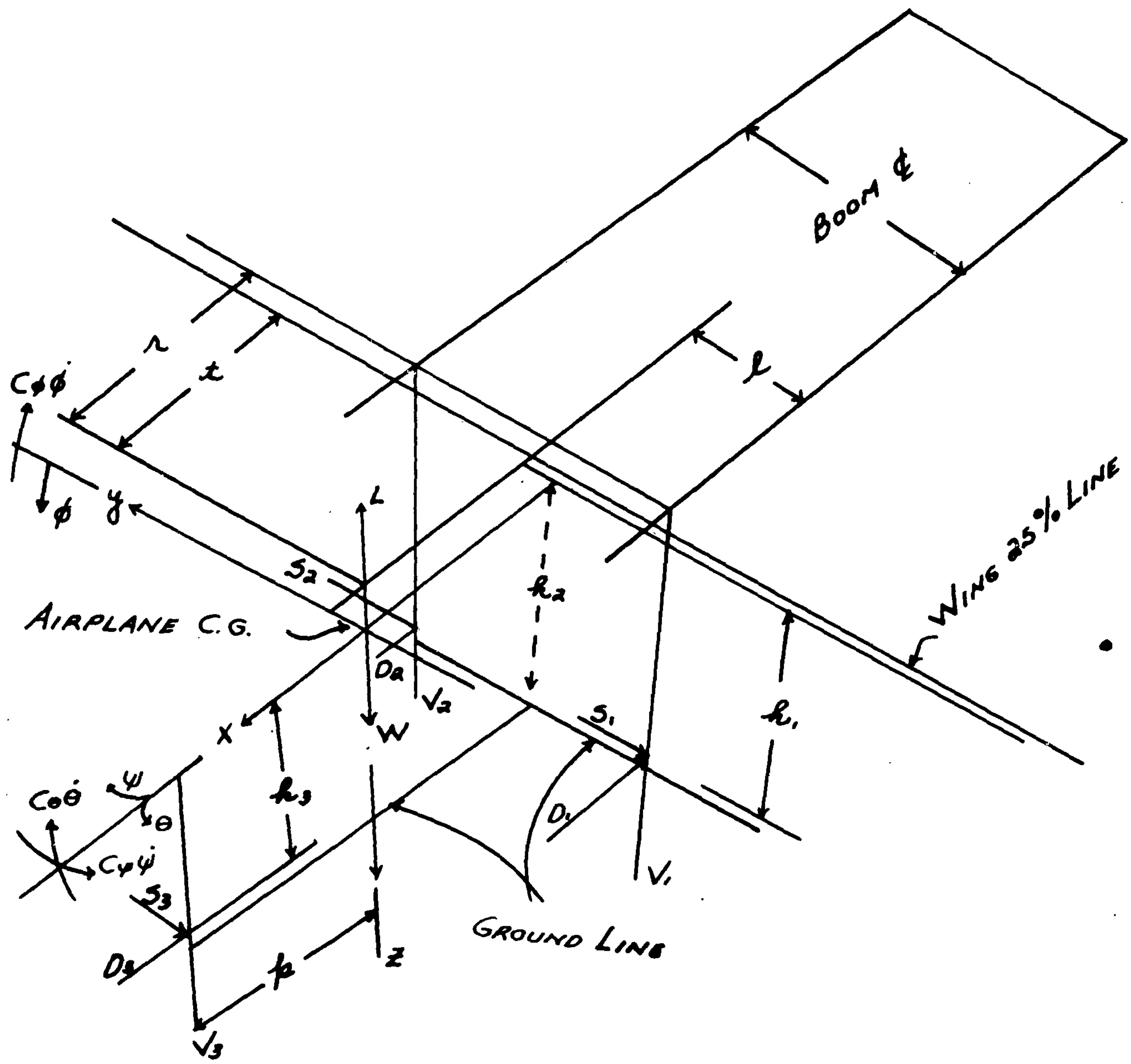


Fig. 3. Geometrical configuration of the airplane during contact of three landing gear units in an unsymmetrical landing maneuver.

landing gear units not in contact with the ground. The equations of motion are

$$M\ddot{x} = -D_1 - D_2 - D_3$$

$$M\ddot{y} = -S_1 - S_2 - S_3$$

$$M\ddot{z} = -V_1 - V_2 - V_3 + W - L \qquad (3)$$

$$I_{xx}\ddot{\varphi} = l\,(V_1 - V_2) + h_1 S_1 + h_2 S_2 + h_3 S_3 - C_\varphi \dot{\varphi}$$

$$I_{yy}\ddot{\theta} = r\,(V_1 + V_2) - p\,V_3 + h_1 D_1 + h_2 D_2 + h_3 D_3 - C_\theta \dot{\theta}$$

$$I_{zz}\ddot{\psi} = r\,(S_1 + S_2) - p\,S_3 + l\,(D_2 - D_1) - C_\psi \dot{\psi}$$

Eqs. (3) are the general equations defining the motion of a tricycle type landing gear during landing. Solution of these equations can be obtained for any airplane for which satisfactory approximations of the time history of the landing gear forces are available. The initial conditions at the beginning of each phase of the landing gear maneuver will depend upon the pilot's commitments prior to contact and the subsequent response of the airplane. In general, all or part of the six coordinates can have initial velocities different from zero at the beginning of any phase. Usually, the origin of the coordinate system will be chosen at the location of the beginning of each phase in order to obtain zero initial displacements of all of the six coordinates.

Derivation for Three Degree of Freedom Case

The typical equivalent system investigated here consists of one having three degrees of freedom, namely, translation, roll, and pitch. In order to provide flexibility for comparison of all types of landing gear configuration, the geometry of the landing gear system is composed of four independently located units. Geometrical parameters are defined so that bicycle, tricycle, and quadricycle landing gear configurations, as well as systems having outrigger gears can be simulated.

A sign convention and geometrical system is chosen so as to somewhat reduce the algebra to a minimum. The initial conditions for each phase of the landing maneuver is established relative to a coordinate system where the origin and the x- and y-axes lie in the runway surface. Zero initial conditions for all of the three degrees of freedom corresponds to point touch contact of all of the landing gear units. This means that the landing gear units are all touching the runway but not yet transmitting forces to the airplane. Of course, necessary alterations must be made to compensate for airplane landing gear designs where the geometry does not permit all landing gear units to touch simultaneously.

A schematic diagram of the airplane equivalent system is shown in Figure 4.

The sign convention is further defined by:

(1) The x- and y-axes are in the plane of the runway surface with x positive forward and y positive to the right.
(2) The z-axis is perpendicular to the runway surface and through the airplane center of gravity with z positive down.
(3) The airplane attitude is defined by θ (pitch) positive nose down and φ (roll) positive right wing down.
(4) Vertical moment arms to the airplane center of gravity for the drag and side forces are h_1, h_2, h_3, and h_4 where the numerical subscript corresponds to the appropriate landing gear unit.

Using the foregoing definitions, the equations of motion are:

$$M\ddot{z} = -V_1 - V_2 - V_3 - V_4 + W - L$$

$$I_{xx}\ddot{\varphi} = -l_1 V_1 - l_2 V_2 - l_3 V_3 - l_4 V_4 + h_1 S_1 + h_2 S_2 + h_3 S_3 + h_4 S_4 \qquad (4)$$

$$I_{yy}\ddot{\theta} = -r_1 V - r_2 V_2 - r_3 V_3 - r_4 V_4 + h_1 D_1 + h_2 D_2 + h_3 D_3 + h_4 D_4$$

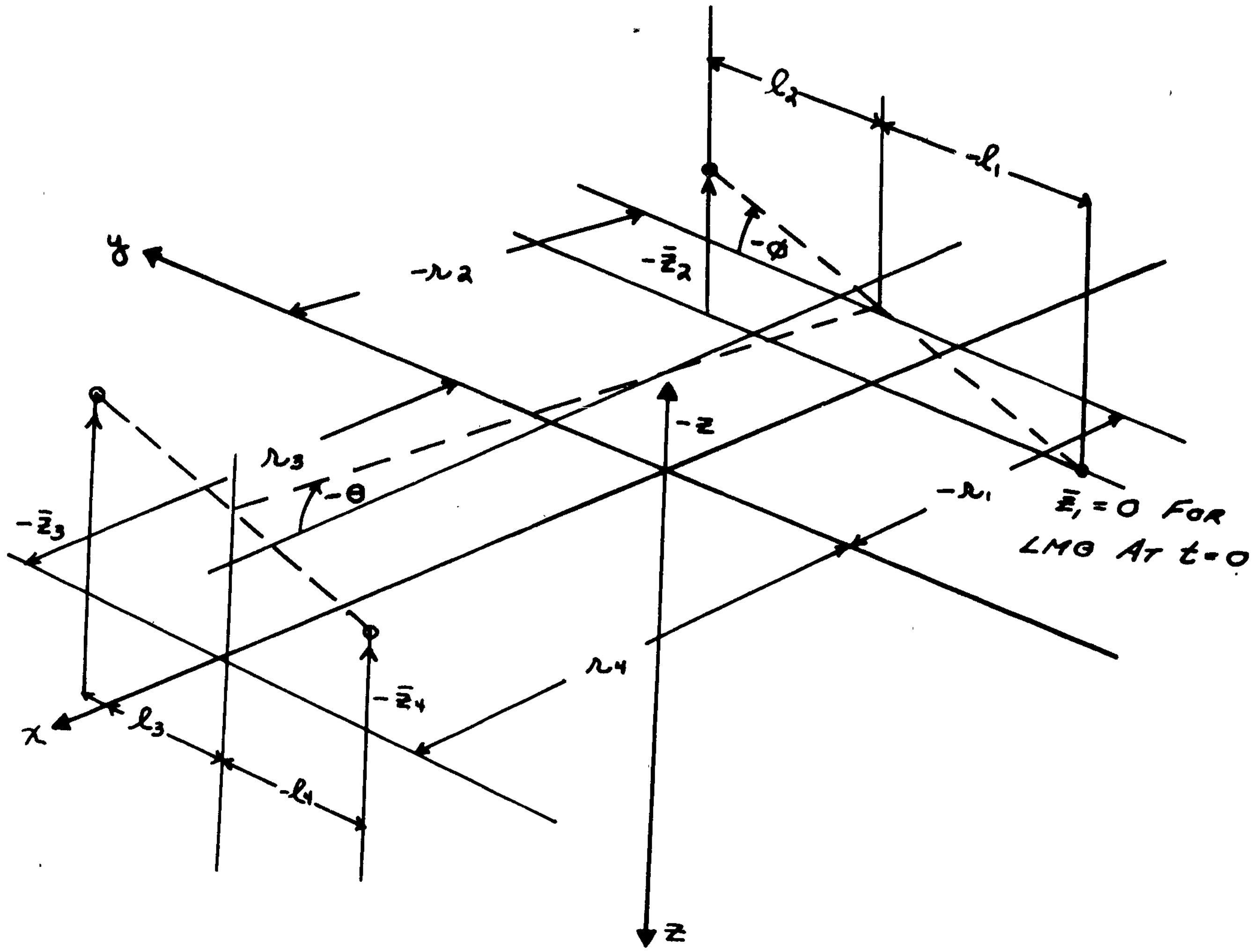


FIGURE 4 GEOMETRY OF AIRPLANE EQUIVALENT SYSTEM SHOWING SIGN CONVENTION.

It is noted that the effect of landing gear deflections has been neglected in the moment arms for the side and drag forces. This assumption appears to be compatible with the approximate nature of the friction coefficients used to obtain these forces. Also, it is pointed out that second order effects of geometrical changes are neglected.

Utilizing the friction coefficients, relationships between the vertical, side and drag forces are as follows:

$$S_i = \mu_s V_i, \text{ and} \tag{5}$$

$$D_i = \mu_d V_i \tag{6}$$

and letting

$$a_i = l_i - h_i \mu_s, \text{ and} \tag{7}$$

$$b_i = r_i - h_i \mu_d \tag{8}$$

The Equations of Motion become

$$\begin{aligned} M\ddot{z} &= - V_1 - V_2 - V_3 - V_4 + W - L \\ I_{xx}\ddot{\varphi} &= - a_1 V_1 - a_2 V_2 - a_3 V_3 - a_4 V_4 \\ I_{yy}\ddot{\theta} &= - b_1 V_1 - b_2 V_2 - b_3 V_3 - b_4 V_4 \end{aligned} \tag{9}$$

Subject to the initial conditions

$$\text{at } t = 0, \qquad \begin{aligned} z &= z_o \\ \varphi &= \varphi_o \\ \theta &= \theta_o \end{aligned} \qquad \begin{aligned} \dot{z} &= \dot{z}_o \\ \dot{\varphi} &= \dot{\varphi}_o \\ \dot{\theta} &= \dot{\theta}_o \end{aligned}$$

The relationship between the vertical location (or deflection) of each landing gear unit and the coordinates of the airplane is given by

$$\bar{z}_i = z + l_i \varphi + r_i \theta \tag{10}$$

Hence, the total kinetic energy of the airplane is given by

$$T = \frac{1}{2} M\dot{z}^2 + \frac{1}{2} I_{xx} \dot{\varphi}^2 + \frac{1}{2} I_{yy} \dot{\theta}^2 \tag{11}$$

Derivation for Effective Mass

The dynamics of the system involving three coordinates is defined by Eqs. (9). However, in order to introduce the concept of effective mass as used in this report it is necessary to make a coordinate transformation that will decouple the system both inertially and elastically. It is noted here this can be accomplished only for one coordinate (or one landing gear unit) at a time. Also, it is necessary that the landing maneuver be restricted to that where only one landing gear unit at a time contacts the runway during the landing rebound and runout period.

For an airplane having three landing gear units, the transformation equations are

$$z = \bar{a}_{11}\,\bar{z}_1 + \bar{a}_{12}\,\bar{z}_2 + \bar{a}_{13}\,\bar{z}_3 \qquad (12)$$

$$\varphi = \bar{a}_{21}\,\bar{z}_1 + \bar{a}_{22}\,\bar{z}_2 + \bar{a}_{23}\,\bar{z}_3 \qquad (13)$$

$$\theta = \bar{a}_{31}\,\bar{z}_1 + \bar{a}_{32}\,\bar{z}_2 + \bar{a}_{33}\,\bar{z}_3 \qquad (14)$$

where

$$\bar{a}_{11} = \frac{1}{\bar{d}}(l_2\,r_3 - l_3\,r_2) \qquad (15)$$

$$\bar{a}_{12} = \frac{1}{\bar{d}}(l_3\,r_1 - l_1\,r_3) \qquad (16)$$

$$\bar{a}_{13} = \frac{1}{\bar{d}}(l_1\,r_2 - l_2\,r_1) \qquad (17)$$

$$\bar{a}_{21} = \frac{1}{\bar{d}}(r_2 - r_3) \qquad (18)$$

$$\bar{a}_{22} = \frac{1}{\bar{d}}(r_3 - r_1) \qquad (19)$$

$$\bar{a}_{23} = \frac{1}{\bar{d}}(r_1 - r_2) \qquad (20)$$

$$\bar{a}_{31} = \frac{1}{\bar{d}}(l_3 - l_2) \qquad (21)$$

$$\bar{a}_{32} = \frac{1}{\bar{d}}(l_1 - l_3) \qquad (22)$$

$$\bar{a}_{33} = \frac{1}{\bar{d}}(l_2 - l_1) \qquad (23)$$

$$\bar{d} = r_1\,(l_3 - l_2) - r_2\,(l_3 - l_1) + r_3\,(l_2 - l_1) \qquad (24)$$

The total kinetic energy of the airplane becomes

$$T = \frac{1}{2} M_{11} \dot{\bar{z}}_1^2 + \frac{1}{2} M_{22} \dot{\bar{z}}_2^2 + \frac{1}{2} M_{33} \dot{\bar{z}}_3^2$$

$$+ M_{12} \dot{\bar{z}}_1 \dot{\bar{z}}_2 + M_{13} \dot{\bar{z}}_1 \dot{\bar{z}}_3 + M_{23} \dot{\bar{z}}_2 \dot{\bar{z}}_3 \tag{25}$$

where

$$\left.\begin{aligned}
M_{11} &= M \bar{a}_{11}^2 + I_{xx} \bar{a}_{21}^2 + I_{yy} \bar{a}_{31}^2 \\
M_{22} &= M \bar{a}_{12}^2 + I_{xx} \bar{a}_{22}^2 + I_{yy} \bar{a}_{32}^2 \\
M_{33} &= M \bar{a}_{13}^2 + I_{xx} \bar{a}_{23}^2 + I_{yy} \bar{a}_{33}^2 \\
M_{12} = M_{21} &= M \bar{a}_{11} \bar{a}_{12} + I_{xx} \bar{a}_{21} \bar{a}_{22} + I_{yy} \bar{a}_{31} \bar{a}_{32} \\
M_{13} = M_{31} &= M \bar{a}_{11} \bar{a}_{13} + I_{xx} \bar{a}_{21} \bar{a}_{23} + I_{yy} \bar{a}_{31} \bar{a}_{33} \\
M_{23} = M_{32} &= M \bar{a}_{12} \bar{a}_{13} + I_{xx} \bar{a}_{22} \bar{a}_{23} + I_{yy} \bar{a}_{32} \bar{a}_{33}
\end{aligned}\right\} \tag{26}$$

And the total work done is

$$\begin{aligned}
\delta W = &\left[- V_i w_1 + (W - L) \bar{a}_{11}\right] \delta\bar{z}_1 \\
&+ \left[- V_i w_2 + (W - L) \bar{a}_{12}\right] \delta\bar{z}_2 \\
&+ \left[- V_i w_3 + (W - L) \bar{a}_{13}\right] \delta\bar{z}_3
\end{aligned}$$

where V_i = total vertical force acting on the ith landing gear unit.

$$\left.\begin{aligned}
w_1 &= \bar{a}_{11} + \bar{a}_{21} a_i + \bar{a}_{31} b_i \\
w_2 &= \bar{a}_{12} + \bar{a}_{22} a_i + \bar{a}_{32} b_i \\
w_3 &= \bar{a}_{13} + \bar{a}_{23} a_i + \bar{a}_{33} b_i
\end{aligned}\right\} \tag{27}$$

Substituting into Lagrange's equation gives the equation of motion as follows

$$\left.\begin{aligned}
M_{11} \ddot{\bar{z}}_1 + M_{12} \ddot{\bar{z}}_2 + M_{13} \ddot{\bar{z}}_3 &= - V_i w_1 + (W - L) \bar{a}_{11} \\
M_{21} \ddot{\bar{z}}_1 + M_{22} \ddot{\bar{z}}_2 + M_{23} \ddot{\bar{z}}_3 &= - V_i w_2 + (W - L) \bar{a}_{12} \\
M_{31} \ddot{\bar{z}}_1 + M_{32} \ddot{\bar{z}}_2 + M_{33} \ddot{\bar{z}}_3 &= - V_i w_3 + (W - L) \bar{a}_{13}
\end{aligned}\right\} \tag{28}$$

Straightforward algebraic methods are used now to complete the transformation to the decoupled system. This is carried out by first solving Eq. (28) for the accelerations $\ddot{\bar{z}}_1$, $\ddot{\bar{z}}_2$, and $\ddot{\bar{z}}_3$.

Then the final equations are obtained by dividing each equation by the corresponding total coefficient of V_i. This gives the following equations of motion.

$$\begin{aligned} M_{1\,eq.}\,\ddot{\bar{z}}_1 &= -V_i + L_1 (W - L) \\ M_{2\,eq.}\,\ddot{\bar{z}}_2 &= -V_i + L_2 (W - L) \\ M_{3\,eq.}\,\ddot{\bar{z}}_3 &= -V_i + L_3 (W - L) \end{aligned} \tag{29}$$

where

$$M_{1\,eq.} = \frac{\bar{M}_1}{\bar{G}_{11}} \tag{30}$$

$$M_{2\,eq.} = \frac{\bar{M}_2}{\bar{G}_{21}} \tag{31}$$

$$M_{3\,eq.} = \frac{\bar{M}_3}{\bar{G}_{31}} \tag{32}$$

$$L_1 = \frac{\bar{G}_{12}}{\bar{G}_{11}} \tag{33}$$

$$L_2 = \frac{\bar{G}_{22}}{\bar{G}_{21}} \tag{34}$$

$$L_3 = \frac{\bar{G}_{32}}{\bar{G}_{31}} \tag{35}$$

$$\bar{M}_1 = \frac{\bar{N}}{M_{22}\,M_{33} - M_{23}\,M_{32}} \tag{36}$$

$$\bar{M}_2 = \frac{\bar{N}}{M_{11}\,M_{33} - M_{13}\,M_{31}} \tag{37}$$

$$\bar{M}_3 = \frac{\bar{N}}{M_{11}\,M_{22} - M_{12}\,M_{21}} \tag{38}$$

$$\begin{aligned} \bar{N} = {} & M_{11} (M_{22}\,M_{33} - M_{23}\,M_{32}) - M_{21} (M_{12}\,M_{33} - M_{13}\,M_{32}) \\ & + M_{31} (M_{12}\,M_{23} - M_{13}\,M_{22}) \end{aligned} \tag{39}$$

$$\bar{G}_{11} = G_{11} w_1 + G_{12} w_2 + G_{13} w_3 \tag{40}$$

$$\bar{G}_{12} = G_{11} \bar{a}_{11} + G_{12} \bar{a}_{12} + G_{13} \bar{a}_{13} \tag{41}$$

$$\bar{G}_{21} = G_{21} w_1 + G_{22} w_2 + G_{23} w_3 \tag{42}$$

$$\bar{G}_{22} = G_{21} \bar{a}_{11} + G_{22} \bar{a}_{12} + G_{23} \bar{a}_{13} \tag{43}$$

$$\bar{G}_{31} = G_{31} w_1 + G_{32} w_2 + G_{33} w_3 \tag{44}$$

$$\bar{G}_{32} = G_{31} \bar{a}_{11} + G_{32} \bar{a}_{12} + G_{33} \bar{a}_{13} \tag{45}$$

$$G_{11} = 1.0 \tag{46}$$

$$G_{12} = - \frac{M_{12} M_{33} - M_{13} M_{32}}{M_{22} M_{33} - M_{23} M_{32}} \tag{47}$$

$$G_{13} = \frac{M_{12} M_{23} - M_{13} M_{22}}{M_{22} M_{33} - M_{23} M_{32}} \tag{48}$$

$$G_{21} = - \frac{M_{21} M_{33} - M_{23} M_{31}}{M_{11} M_{33} - M_{13} M_{31}} \tag{49}$$

$$G_{22} = 1.0 \tag{50}$$

$$G_{23} = - \frac{M_{11} M_{23} - M_{13} M_{21}}{M_{11} M_{33} - M_{13} M_{31}} \tag{51}$$

$$G_{31} = \frac{M_{21} M_{32} - M_{22} M_{31}}{M_{11} M_{22} - M_{12} M_{21}} \tag{52}$$

$$G_{32} = - \frac{M_{11} M_{32} - M_{12} M_{31}}{M_{11} M_{22} - M_{12} M_{21}} \tag{53}$$

$$G_{33} = 1.0 \tag{54}$$

This completes the coefficients required for Eqs. (29). It is noted that the equation for the i^{th} landing gear unit is completely decoupled. Hence, its mass term is the effective mass acting on the landing gear unit in contact with the runway. The other two mass terms for the landing gear units not in contact with the runway have no simple physical interpretation.

For the purpose of studying the effect of geometrical, inertial, and external force parameters, it is assumed that a good approximation of any force-time history generated by a landing gear unit can be obtained from the proper choice of a linear spring and a viscous damper. Once chosen, the spring rate and the damping coefficients must remain constant throughout the impact. However, it is conceivable that a landing gear unit could have several sets of spring rates and damping coefficients to produce the variety of force-time histories obtainable from various types of hard and soft landing impacts.

Hence, let

$$V_i = C_i \dot{\bar{z}}_i + K_i \bar{z}_i \tag{55}$$

Then Eqs. (29) become

$$\begin{aligned} M_{1\,eq.} \ddot{\bar{z}}_1 + C_i \dot{\bar{z}}_i + K_i \bar{z}_i &= L_1 (W - L) \\ M_{2\,eq.} \ddot{\bar{z}}_2 + C_i \dot{\bar{z}}_i + K_i \bar{z}_i &= L_2 (W - L) \\ M_{3\,eq.} \ddot{\bar{z}}_3 + C_i \dot{\bar{z}}_i + K_i \bar{z}_i &= L_3 (W - L) \end{aligned} \tag{56}$$

In this form, the equations permit the study of the individual response of each landing gear unit to the landing forces. The initial conditions are

$$\begin{aligned} \text{at } t = 0,\ & \bar{z}_1 = \bar{z}_{10},\ \bar{z}_2 = \bar{z}_{20},\ \bar{z}_3 = \bar{z}_{30}, \\ & \dot{\bar{z}}_1 = \dot{\bar{z}}_{10},\ \dot{\bar{z}}_2 = \dot{\bar{z}}_{20},\ \dot{\bar{z}}_3 = \dot{\bar{z}}_{30} \end{aligned}$$

For the landing gear unit in contact with the runway (i.e. i^{th} unit), the displacement, velocity, and acceleration become

$$\bar{Z}_i = J_{io} + J_{i3}\, e^{\gamma t} \sin \eta t + J_{i4} \cos \eta t \tag{57}$$

$$\begin{aligned} \dot{\bar{Z}}_i = {} & J_{i3} (\eta e^{\gamma t} \cos \eta t + \gamma e^{\gamma t} \sin \eta t) \\ & + J_{i4} (\gamma e^{\gamma t} \cos \eta t - \eta\, e^{\gamma t} \sin \eta t) \end{aligned} \tag{58}$$

$$\begin{aligned} \ddot{\bar{Z}}_i = {} & J_{i3} \left[(\gamma^2 - \eta^2)\, e^{\gamma t} \sin \eta t + 2 \gamma \eta\, e^{\gamma t} \cos \eta t\right] \\ & + J_{i4} \left[(\gamma^2 - \eta^2)\, e^{\gamma t} \cos \eta t - 2 \gamma \eta\, e^{\gamma t} \sin \eta t\right] \end{aligned} \tag{59}$$

where

$$\gamma = - \frac{C_i}{2 M_{i\,eq.}} \tag{60}$$

$$\eta = \sqrt{\frac{K_i}{M_i \text{ eq.}} - \left(\frac{C_i}{2\, M_i \text{ eq.}}\right)^2} \tag{61}$$

$$J_{io} = \frac{L_i\,(W - L)}{K_i} \tag{62}$$

$$J_{i3} = \frac{1}{\eta} \left\{ \dot{\bar{z}}_{io} - \xi \left[\bar{z}_{io} - \frac{L_i\,(W - L)}{K_i} \right] \right\} \tag{63}$$

$$J_{i4} = \bar{z}_{io} - \frac{L_i\,(W - L)}{K_i} \tag{64}$$

The general equations for either of the two landing gear units not in contact with the runway are obtained by integrating twice with respect to time. This gives the following equations for the displacement, velocity, and acceleration of the j^{th} landing gear unit.

$$\begin{aligned} \bar{z}_j = {} & J_{jo} + J_{j1}\, t + J_{j2}\, t^2 + J_{j3}\, e^{\xi t} \sin \eta t \\ & + J_{j4}\, e^{\xi t} \cos \eta t \end{aligned} \tag{65}$$

$$\begin{aligned} \dot{\bar{z}}_j = {} & J_{j1} + 2\, J_{j2}\, t + J_{j3}\, (\eta\, e^{\xi t} \cos \eta t + \xi\, e^{\xi t} \sin \eta t) \\ & + J_{j4}\, (\xi\, e^{\xi t} \cos \eta t - \eta\, e^{\xi t} \sin \eta t) \end{aligned} \tag{66}$$

$$\begin{aligned} \ddot{\bar{z}}_j = {} & 2\, J_{j2} + J_{j3} \left[(\xi^2 - \eta^2)\, e^{\xi t} \sin \eta t + 2\, \xi\, \eta\, e^{\xi t} \cos \eta t \right] \\ & + J_{j4} \left[(\xi^2 - \eta^2)\, e^{\xi t} \cos \eta t - 2\, \xi\, \eta\, e^{\xi t} \sin \eta t \right] \end{aligned} \tag{67}$$

where

$$\begin{aligned} J_{jo} = {} & \frac{1}{M_j \text{ eq.}} \left\{ \bar{z}_{jo} + \left(\frac{M_i \text{ eq.}}{K_i} \right)^2 \left[(\xi^2 - \eta^2)\, (\xi\, C_i\, J_{i4} + \eta\, C_i\, J_{i3} \right. \right. \\ & \left. \left. + K_i\, J_{i4}) - 2\xi\, \eta\, (\xi C_i\, J_{i3} - \eta\, C_i\, J_{i4} + K_i\, J_{i3}) \right] \right\} \end{aligned} \tag{68}$$

$$\begin{aligned} J_{j1} = {} & \frac{1}{M_j \text{ eq.}} \left\{ \dot{\bar{z}}_{jo} + \frac{M_i \text{eq.}}{K_i} \left[\eta\, (-\xi\, C_i\, J_{i3} + \eta\, C_i\, J_{i4} - K_i\, J_{i3}) \right. \right. \\ & \left. \left. + \xi\, (\xi\, C_i\, J_{i4} + \eta\, C_i\, J_{i3} + K_i\, J_{i4}) \right] \right\} \end{aligned} \tag{69}$$

$$J_{j2} = \frac{(L_j - L_i)\,(W - L)}{2\, M_j \text{ eq.}} \tag{70}$$

$$J_{j3} = \frac{1}{M_{j\ eq.}} \left(\frac{M_{i\ eq.}}{K_i}\right)^2 \left\{ (\zeta^2 - \eta^2)(-\zeta C_i J_{i3} + \eta C_i J_{i4} - K_i J_{i3}) \right.$$

$$\left. - 2\zeta\eta(\zeta C_i J_{i4} + \eta C_i J_{i3} + K_i J_{i4}) \right\} \qquad (71)$$

$$J_{j4} = \frac{1}{M_{j\ eq.}} \left(\frac{M_{i\ eq.}}{K_i}\right)^2 \left\{ -(\zeta^2 - \eta^2)(\zeta C_i J_{i4} + \eta C_i J_{i3} + K_i J_{i4}) \right.$$

$$\left. + 2\zeta\eta(\zeta C_i J_{i3} - \eta C_i J_{i4} + K_i J_{i3}) \right\} \qquad (72)$$

Using Eqs. (57) through (72) inclusive, the complete response time-histories of any landing impact can be calculated for any three landing gear units. In this form, the equations permit optimum flexibility for independently studying the characteristics of each landing gear unit. A similar process can be used for the nonlinear case using numerical methods.

The motion of the airplane in free flight is given by

$$\left.\begin{aligned} \ddot{\bar{z}}_1 &= \frac{L_1 (W - L)}{M_{1\ eq.}} \\ \ddot{\bar{z}}_2 &= \frac{L_2 (W - L)}{M_{2\ eq.}} \\ \ddot{z}_3 &= \frac{L_3 (W - L)}{M_{3\ eq.}} \end{aligned}\right\} \qquad (73)$$

With the initial conditions

$$\text{at } t = 0,\ \bar{z}_1 = \bar{z}_{10},\ \bar{z}_2 = \bar{z}_{20},\ \bar{z}_3 = \bar{z}_{30},$$

$$\dot{\bar{z}}_1 = \dot{\bar{z}}_{10},\ \dot{\bar{z}}_2 = \dot{\bar{z}}_{20},\ \text{and } \dot{\bar{z}}_2 = \dot{\bar{z}}_{30}$$

for which the solutions are

$$\left.\begin{aligned} \bar{z}_1 &= \bar{z}_{10} + \dot{\bar{z}}_{10} t + \frac{1}{2} \frac{L_1 (W - L)}{M_{1\ eq.}} t^2 \\ \bar{z}_2 &= \bar{z}_{20} + \dot{\bar{z}}_{20} t + \frac{1}{2} \frac{L_2 (W - L)}{M_{2\ eq.}} t^2 \\ \bar{z}_3 &= \bar{z}_{30} + \dot{\bar{z}}_{30} t + \frac{1}{2} \frac{L_3 (W - L)}{M_{3\ eq.}} t^2 \end{aligned}\right\} \qquad (74)$$

$$
\left.
\begin{aligned}
\dot{\bar{z}}_1 &= \dot{\bar{z}}_{10} + \frac{L_1 (W - L)}{M_{1\,eq.}}\, t \\
\dot{\bar{z}}_2 &= \dot{\bar{z}}_{20} + \frac{L_2 (W - L)}{M_{2\,eq.}}\, t \\
\dot{\bar{z}}_3 &= \dot{\bar{z}}_{30} + \frac{L_3 (W - L)}{M_{3\,eq.}}\, t
\end{aligned}
\right\} \qquad (75)
$$

Where the total time of free flight is given by the following equations for $(W - L) = 0$

$$
t = - \frac{\bar{z}_{io}}{\dot{\bar{z}}_{io}} \qquad (76)
$$

for $(W - L) \neq 0$

$$
t = - \frac{M_{i\,eq.}\, \dot{\bar{z}}_{io}}{L_i (W - L)} + \sqrt{\left[\frac{M_{i\,eq.}\, \dot{\bar{z}}_{io}}{L_i (W - L)}\right]^2 - \frac{2 M_{i\,eq.}\, \bar{z}_{io}}{L_i (W - L)}} \qquad (77)
$$

In this case, the i^{th} unit is the first landing gear to contact after free flight.

The equation for the force at any instant of time is given by Eq. (55). Hence, the time at which the maximum force occurs is obtained by setting the derivative with respect to time equal to zero. This yields

$$
t_m = \frac{1}{\eta} \sin^{-1} \frac{\bar{R}}{\sqrt{1 + \bar{R}^2}} \qquad (78)
$$

where

$$
R = \frac{\eta K_i J_{i3} + \gamma K_i J_{i4} + 2\gamma C_i J_{i3} + (\gamma^2 - \eta^2) C_i J_{i4}}{-\gamma K_i J_{i3} + \eta K_i J_{i4} + 2\gamma\eta C_i J_{i4} - (\gamma^2 - \eta^2) C_i J_{i3}} \qquad (79)
$$

The time at which the maximum force occurs is obtained from Eq. (78). Substituting this time into Eq. (55) gives the maximum force generated during the impact on the i^{th} landing gear unit.

Discussion of Correlation with Drop Test Requirements

In the previous section of this report, equations are shown in terms of the effective mass acting on each landing gear unit. The equation for the landing gear unit in contact with the runway (i^{th} unit) is shown as follows

$$M_{i\,eq.}\ \ddot{\bar{z}}_i + V_i = L_i\ (W - L) \qquad (80)$$

Subject to the initial conditions

at $t = 0$, $\bar{z}_i = \bar{z}_{io}$, and $\dot{\bar{z}}_i = \dot{\bar{z}}_{io}$

Where V_i is the total vertical forcing function acting on the i^{th} landing gear unit.

It can be seen that only one degree of freedom is involved in Eq. (80). However, drop test calculations are usually based upon two degrees of freedom. The equations of motion for a typical drop test configuration are shown as follows

$$M_{eq.}\ \ddot{z} + V = W_{eq.} \qquad (81)$$

$$m\ddot{\zeta} - V + F_t = w \qquad (82)$$

where

z = vertical displacement of dropped mass

ζ = vertical displacement of wheel axle

$M_{eq.}$ and $W_{eq.}$ = mass and weight of dropped mass

m and w = mass and weight of wheel assembly

V = total vertical force acting in strut

F_t = total vertical force acting on tire

If it is assumed that the effective mass term in Eq. (80) does not include the mass of the wheel assembly, the left sides of Eqs. (80) and (81) are compatible. To obtain correlation with the right sides of these equations it is necessary that the airplane have a wing lift such that

$$W_{eq.} = L_i\ (W - L)$$

or

$$\frac{L}{W} = 1 - \frac{M_{i\,eq.}}{L_i\ M} \qquad (83)$$

Numerical calculations have shown that this equality, Eq. (80) , checks for the case of zero wing lift and with no applied side or drag forces.

Eqs. (81) and (82) have been solved successfully for drop test configurations using numerical techniques. In these solutions all known factors pertaining to the nonlinear characteristics have been included. For example, nonlinear tire, oleo air, and oleo orifice flow data has been used. A reasonable approximation of these nonlinear effects on the airplane can be obtained by replacing Eq. (80) by Eqs. (81) and (82) and utilizing the known numerical methods of calculation.

SECTION II: CALCULATED RESULTS AND CORRELATION WITH FLIGHT TEST DATA

Calculating Machine Techniques

The IBM Card-Programmed Electronic Calculator was used for the large scale calculations made in connection with this report. General purpose control panels were used having all of the operations needed. The analytical equations were programmed for sequential calculations on the machines. The calculations were performed entirely on a floating decimal basis. Numerical symbols were introduced to represent the algebraic symbols of the analytical work. These symbols were punched in cards in such a manner that they appeared opposite the answers as required. In addition, a minor deck programming system was employed where each minor deck could be treated as a unit of calculation. Using this technique the large decks were built up by programming the minor decks and repeating them wherever necessary. This expedited the checking because, whereas a minor deck might be used ten times, it was only necessary to check the one original. Wherever possible, numerical data were substituted back in the original differential equations in the actual programming. This means that every calculation was automatically checked by the calculating machine. Each airplane landing response calculation was divided into phases depending upon the character of the forces acting. For example, the period during which the direct force acted on the landing gear was designated as Phase 1 for that landing gear unit. The remainder of the time during which that landing gear unit was in contact with the runway was designated as Phase 2. Phase 3 was reserved for the duration of time between impacts. Denoting the landing gear units with Number 1 for left main gear, Number 2 for right main gear, and Number 3 for nose gear completed the definition of a landing phase. For example, 201 denotes Phase 2 for landing gear Number 1, and 312 denotes Phase 3 or free-flight from landing gear 1 to landing gear 2. Numerical calculations were made for six airplanes, namely, C-119-B, XC-120, C-119H, B-36, F-84, and C-47. Parameter variations were made to show the effect of wing-lift, lateral distance from centerline of the airplane to the main landing gear unit, fore and aft location of the c.g. relative to the landing gear configuration, side load, flexibility of the landing gear unit, and damping characteristics of the landing gear unit.

These calculations were performed for three rates of descent, namely, 12 ft. per second, 8 ft. per second, and 4 ft. per second. In each case the initial rate of descent and maximum force was calculated for the landing impact.

Comparison of Calculated and Measured Response Data

For this investigation several landing tests were conducted using the C-119-H airplane. Various landing techniques were employed in order to try to accentuate the unsymmetrical landing characteristics of the airplane. Since several of the tests were conducted leaving the technique entirely up to the judgment of the pilot, some of the landing records show somewhat unorthodox use of the control surfaces dur-

ing the landing maneuver. However, it is considered significant that approximately 40% of the landings indicated a higher reaction on the second main landing gear to contact the runway. In no case was a landing maneuver executed in which the nose gear contacted the runway before the second main landing gear. This is probably due to the fact that the c.g. of the airplane is located fairly close to the axis of the main landing gear in a fore and aft direction.

Extensive statistical data have been compiled from these landing tests for comparison with landing test data from other airplanes available for this study. The other airplanes included are the C-119 G, F-84 E, B-36, and C-47. Although this represents a considerable quantity of test data, a complete statistical picture of the problem is not presented in this report. It should be noted here that the scope of the work to be accomplished by this report is limited to studies of the severity of a subsequent impact relative to the first impact and to derive methods that will lead to improvement in the existing landing gear design criteria. A large quantity of landing analyses have been made using the IBM Card-programmed Electronic Calculator in order to present statistical data showing the severity of the second impact relative to the first. Tables and charts have been prepared showing the results of these analyses. The results have shown that the second main landing gear unit impacts are harder than the first. Most important is the effect of location of the landing gear unit on the airplane. The data, of course, lead to a fuller understanding of the dynamical problem, however, they leave the main question in regard to landing gear design criteria unanswered. The basic problem of the landing gear design engineer is to determine the magnitudes of the design loads to be applied to each landing gear unit of the airplane. In order for him to do this, it is necessary to arrive at a criterion taking into account all of the factors mentioned above. It appears that this criterion can best be obtained as a modification of the existing criterion. For example, suppose that based upon past experience, a basic rate of descent of say 8 or 9 feet per second is agreed upon. A magnification factor dependent upon the geometric, inertial, and external force characteristics is then used to increase the basic rate of descent data to be used for designing each landing gear unit. Of course, a different magnification factor would be expected for a nose gear as opposed to a main gear. The actual load factors to be used for the landing gear design will still depend upon the geometrical, inertial, and external force data for the airplane as well as the flexibility and damping characteristics of each landing gear unit. The basis for a nose gear design criterion is somewhat more difficult. This results from the influence of pilot technique in manipulating the control surfaces during the landing maneuver. This brings in the aerodynamic performance characteristics of the airplane. For example, it is conceivable that an airplane having a very powerful elevator might never contact the runway with its nose gear during the initial phases of a landing. It appears that the usual pilot technique employed during landings is to hold the nose gear off the runway until the airplane has slowed down considerably. However, theoretical calculations shown in this report indicate that for a very hard landing it might not be possible to hold the nose gear off. The effect of pilot technique is not included in the computations shown in this report.

Several factors contribute to the complication of the analysis of the initial impact. In addition to initial yawing and pitching moments that can be supplied by the pilot, initial velocities in all of these degrees of freedom can be present as a result of some previous technique before the first landing impact. However, it is shown in this report that by far the most important parameter for any impacts is the linear-vertical velocity of that landing gear unit. This is as it should be since all existing landing gear criteria are based upon this parameter.

It is to be noted that the majority of the statistical calculations tabulated in this report are based upon rigid body motion of the airplane. Hence, consideration of the airplane flexibility constitutes another phase of the landing gear design problem. It is recommended here that future design criteria provide for each airplane manufacturer to conduct approximate dynamical analyses to take into account airplane flexibilities. This recommendation is made primarily because it is the only approach that will yield an adequate distribution of dynamical stress throughout the airplane.

It is to be noted that rigid body dynamics has been used for the majority of the statistical calculations tabulated in this report. The problem of airplane flexibility and its effect on the detailed stress distribution throughout the airplane present complications beyond the scope of this report.

The initial numerical work for this report was set up so that the dynamic response of the airplane could be obtained for an arbitrary forcing function. Figures 9a and 9b show the results of one of these calculations. The forcing function was obtained as force versus displacement from drop test data.

This approach was abandoned for most of the work shown in this report because of the lack of drop test data from which to obtain forcing functions for all of the airplanes analyzed. Also, it was considered important to sacrifice accuracy somewhat with the view to develop equations more useful to the study of design criteria for landing gears.

Figures 5, 6, 7, and 8 show the comparison between landing test data and response data calculated by the methods shown in this report. Although exact duplication was not obtained, the results show that the characteristic behavior of the dynamical systems have been simulated. The data shown pertains to the F-84 E, C-47, C-119 H, and B-36 airplanes.

Factual Data for the F-84 E Airplane for Landing Test 4-5

$$l_1 = -52.5 \text{ inches}$$

$$r_1 = -15 \text{ inches}$$

$$r_3 = 128.4 \text{ inches}$$

$$M = 34.3 \text{ lb-in}^{-1}\text{-sec}^2$$

$I_{xx} = 3.98 \times 10^5$ lb-in-sec.^{2} with tip tanks

$I_{yy} = 1.61 \times 10^5$ lb-in-sec.^{2}

$h_1 = 54.4$ inches

$h_2 = 54.4$ inches

$h_3 = 64.8$ inches

$W = 13{,}239$ lbs.

$\dot{\bar{z}}_{10} = 35.0$ in./sec.

$\dot{\bar{z}}_{20} = 42.5$ in./sec.

Factual Data for C-47 Airplane for Landing Test 2-4

$(z)_o = -\ 0.44$ inches

$(\varphi)_o = .0124$ rad. left

$(\theta)_o = .0272$ rad. nose up

$(\bar{z}_1)_o = 0$

$(\bar{z}_2)_o = -\ 2.75$ inches

$(\bar{z}_3)_o = -\ 78.3$ inches

$l_1 = -\ 111$ inches

$r_1 = -\ 34.7$ inches

$M = 60.1$ lb-in^{-1} sec.^{2}

$I_{xx} = 5.6 \times 10^5$ lb-in-sec.^{2}

$I_{yy} = 9.35 \times 10^5$ lb-in-sec.^{2}

$h_1 = 109$ inches

$h_2 = 109$ inches

$h_3 = 19.3$ inches

$r_3 = 406.8$ inches

$W = 23{,}185$ lbs.

$\dot{\bar{z}}_{10} = 27$ in./sec.

$\dot{\bar{z}}_{20} = 40.5$ in./sec.

Factual Data for C-119-H Airplane for Landing Test 12

$(z)_o$ = - 9.78 inches

$(\varphi)_o$ = 2.6° L

$(\theta)_o$ = 3.4° Up

$(\bar{z}_1)_o$ = 0

$(\bar{z}_2)_o$ = - 17.01 inches

$(\bar{z}_3)_o$ = - 28.02 inches

l_1 = - 18.75 inches

r_1 = - 21.37 inches

M = 172.3 lb-in^{-1} sec.^{2}

I_{xx} = 9.03×10^6 lb-in-sec.^{2}

I_{yy} = 5.72×10^6 lb-in-sec.^{2}

h_1 = 117.2 inches

h_2 = 117.2 inches

h_3 = 117.68 inches

r_3 = 307.68 inches

W = 66,500 lbs.

$\dot{z}_{10}$ = 35 in/sec.

$\dot{z}_{20}$ = 48 in/sec.

Factual Data for B-36 Airplane

l_1 = - 276 inches

r_1 = - 96 inches

r_3 = 612 inches

M = 850 lbs-sec.^{2}/inch

I_{xx} = 1.54×10^8 inch-lbs-sec.^{2}

I_{yy} = 8.26×10^7 inch-lbs-sec.^{2}

h_1 = 216 inches

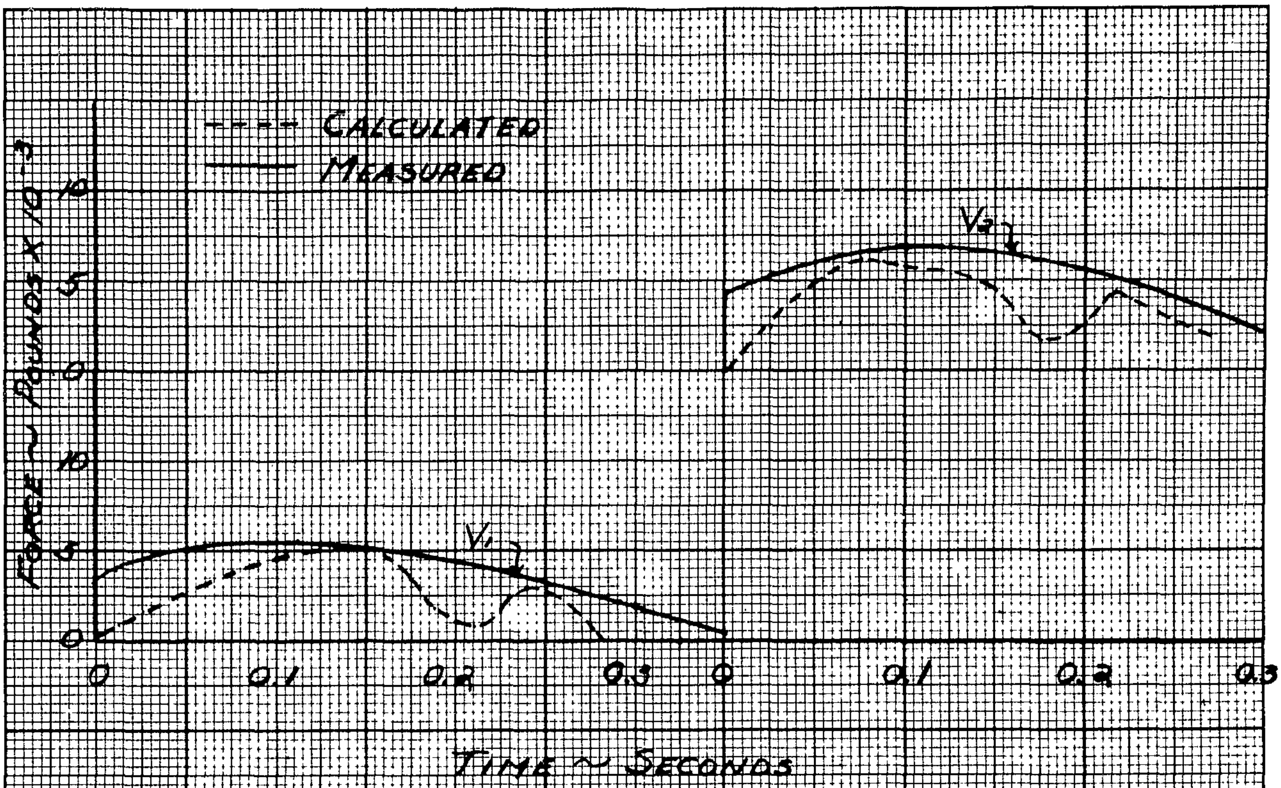


FIGURE 5 CALCULATED AND MEASURED LANDING FORCES FOR F-84E AIRPLANE

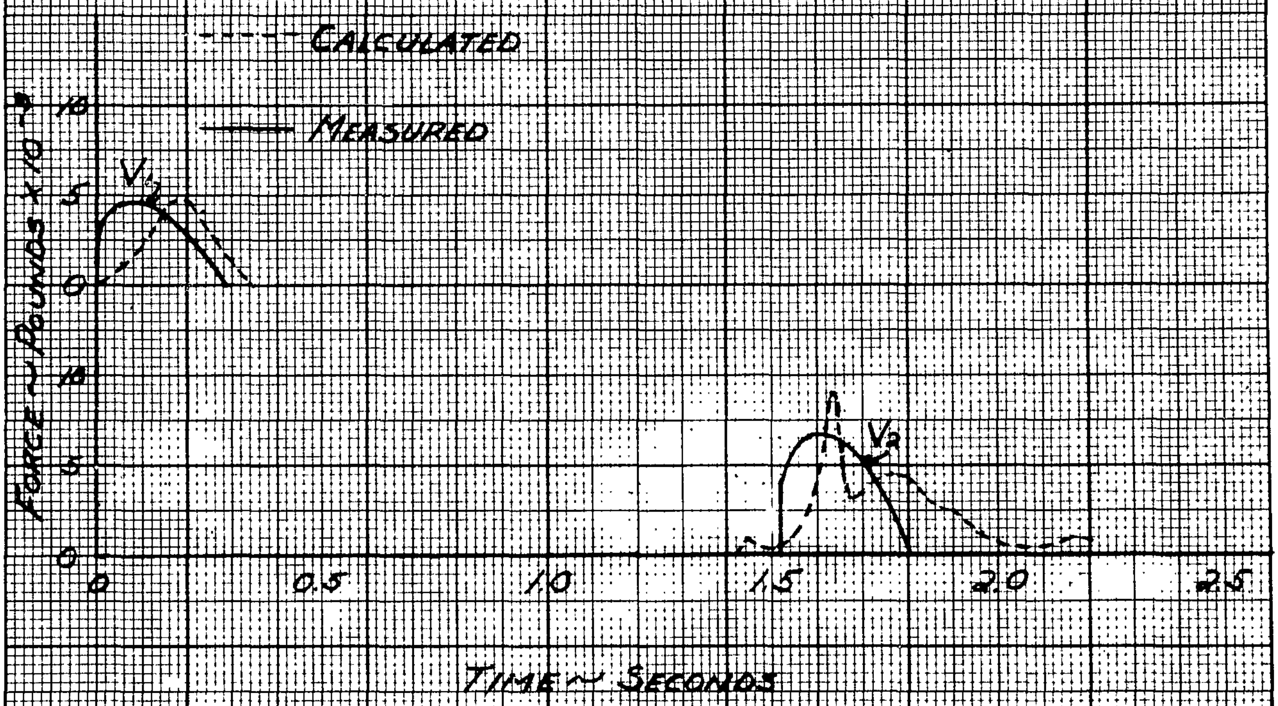


FIGURE 6 CALCULATED AND MEASURED LANDING FORCES FOR C-47 AIRPLANE

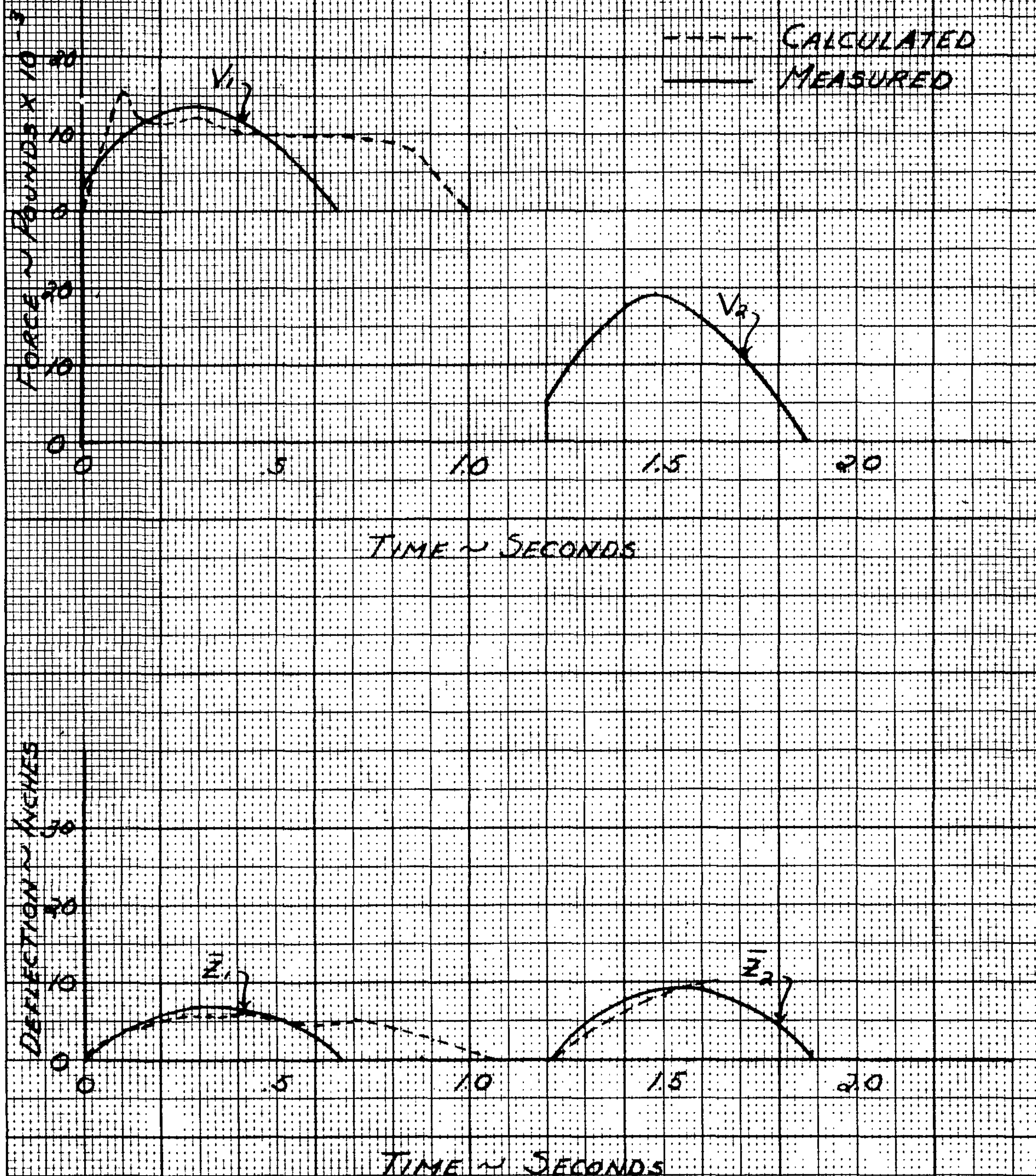


FIGURE 7 CALCULATED AND MEASURED LANDING FORCES AND DISPLACEMENTS FOR C-119H AIRPLANE

FIGURE 8 CALCULATED AND MEASURED LANDING FORCES FOR B-36 AIRPLANE.

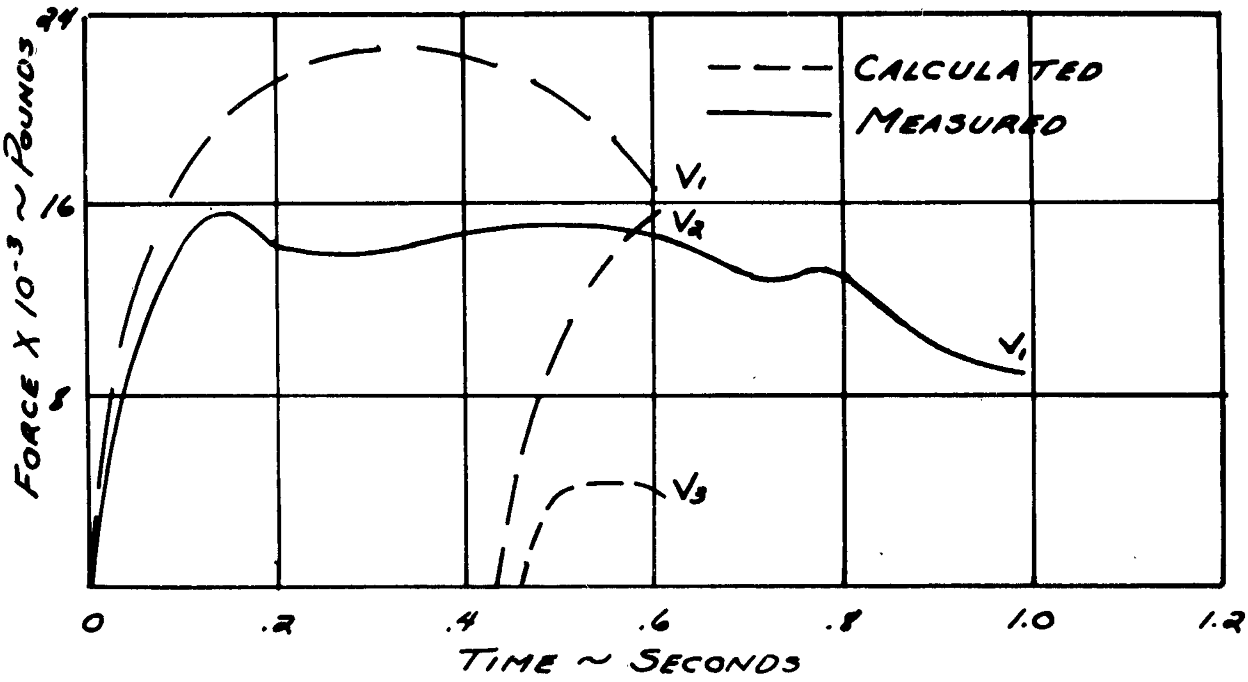


FIGURE 9a CALCULATED AND MEASURED VERTICAL FORCES ACTING ON LANDING GEARS.

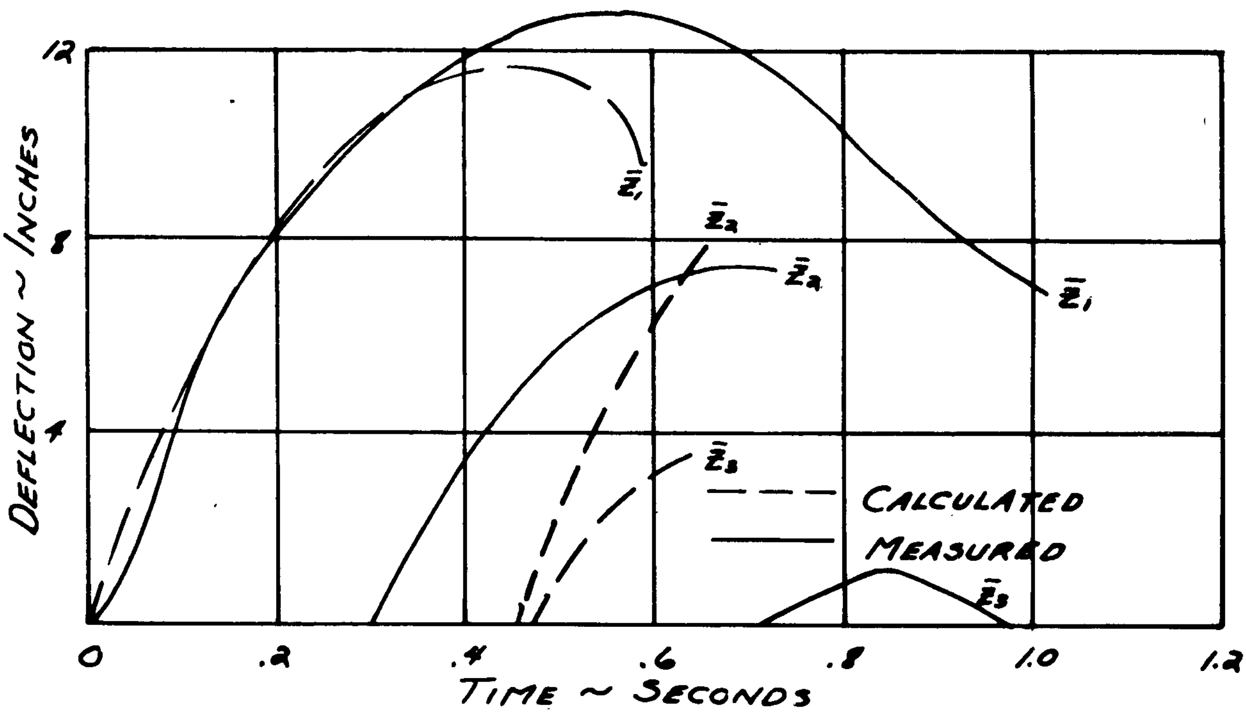


FIGURE 9b CALCULATED AND ACTUAL GEAR DEFLECTIONS

$h_2 = 216$ inches

$h_3 = 197.6$ inches

$W = 328{,}000$ lbs.

$\dot{Z}_{10} = 50$ in/sec

$(\dot{Z}_{10})$(second impact) $= 29$ in/sec

Comparison with Impulse - Momentum Methods

Reference 18 shows derivations for the initial contact conditions for subsequent impacts based upon an impulse-momentum theory. Essentially, the method is based upon the usual assumptions completely linearizing the problem except in regard to the so-called landing gear forcing functions. Equations are shown for several landing maneuvers involving one or more landing gear units at the same time. These equations yield the initial conditions for the next phase of the landing maneuver. An analysis of an airplane can be performed by several steps where the final conditions of each step are used for the initial conditions for the following step. The momentum relations for an airplane which contacts the runway on one landing gear only will yield two equations; however, three unknown parameters are necessary to determine the dynamical response of the system. Hence, it is necessary in this case to introduce an empirical equation based upon a relation with the overall landing gear efficiency. This provides the third equation so that a solution can be obtained. As the number of landing gear units in contact with the runway is increased, a corresponding number of empirical equations must be introduced. For example, with two landing gear units in contact with the runway, it is neccessary to add two empirical equations. From the standpoint of obtaining initial contact conditions for subsequent impacts, this is a very ingenious technique since considerable data are available for the overall efficiency of all kinds of landing gear units. However, having the initial conditions, the design engineer is still faced with the problem of determining the magnitude of the forces acting on the landing gear units.

A derivation for effective mass is shown also based upon the impulse-momentum theory. The effect of all the geometric, inertial, and force parameters appear to be included in these equations. However, it is not shown that the derived effective mass meets a tangible definition in relation to the dynamical system. In the first place, a clarification should be made as to the use of the term "effective mass" in connection with landing gear design criteria. It is a practice in general dynamical analyses to use the term "equivalent mass" in a rather broad sense. Wherever two coordinate systems are used, the concept of an equivalent system is usually introduced. The first set of coordinates fundamentally defines the dynamical system, whereas the second set is chosen in order to arrange the equations in a manner more suitable for numerical evaluations. The mass terms in the equations relating the second set of coordinates are usually de-

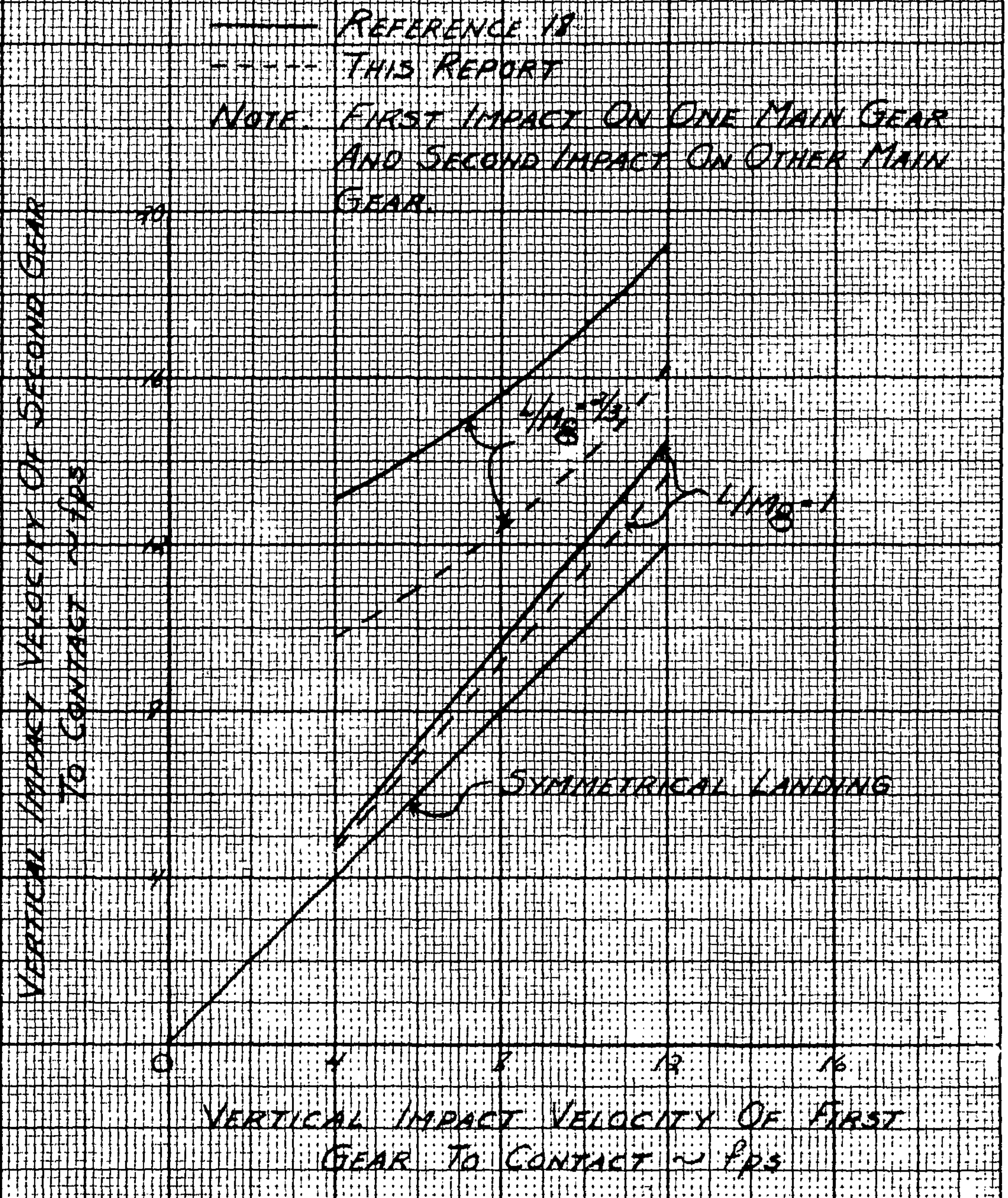


FIGURE 10 COMPARISON OF LANDING-GEAR CONTACT VELOCITIES BETWEEN THIS REPORT AND IMPULSE-MOMENTUM METHOD SHOWING EFFECT OF WING LIFT.

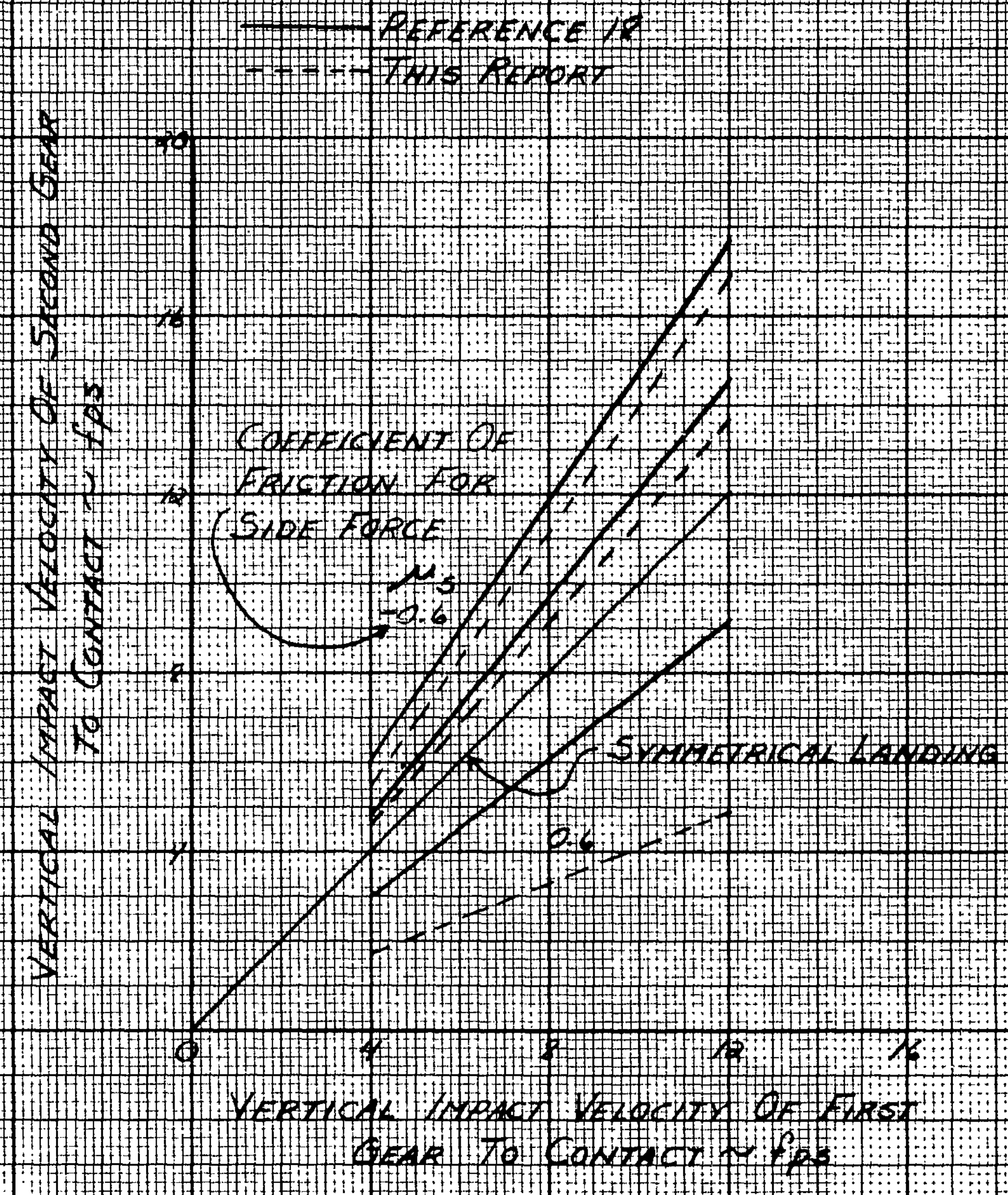


FIGURE 11 COMPARISON OF LANDING - GEAR CONTACT VELOCITIES BETWEEN THIS REPORT AND IMPULSE - MOMENTUM METHOD SHOWING EFFECT OF SIDE FORCES.

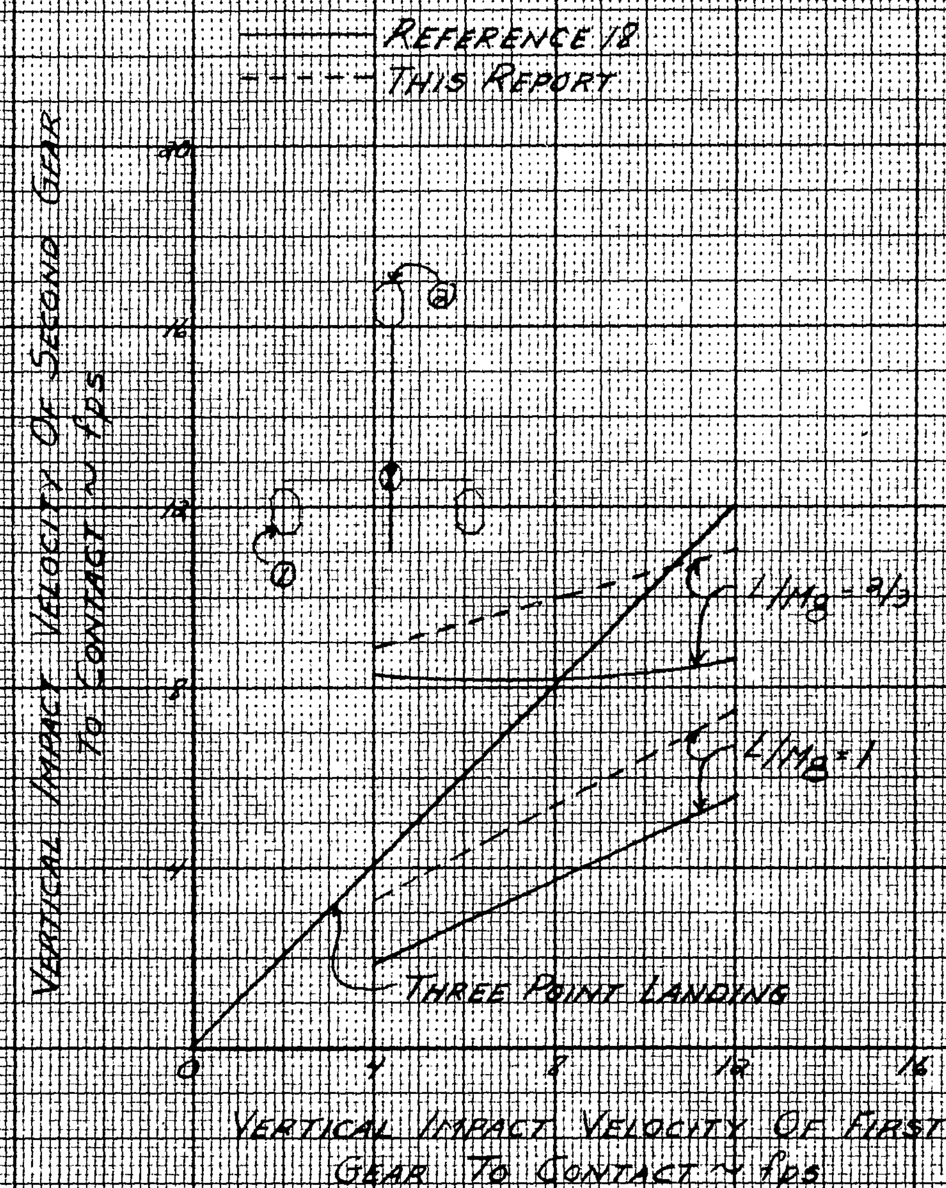


FIGURE 12 COMPARISON OF LANDING-GEAR CONTACT VELOCITIES BETWEEN THIS REPORT AND THE IMPULSE-MOMENTUM METHOD FOR SECOND IMPACT ON NOSE GEAR OF TRICYCLE AIRPLANE.

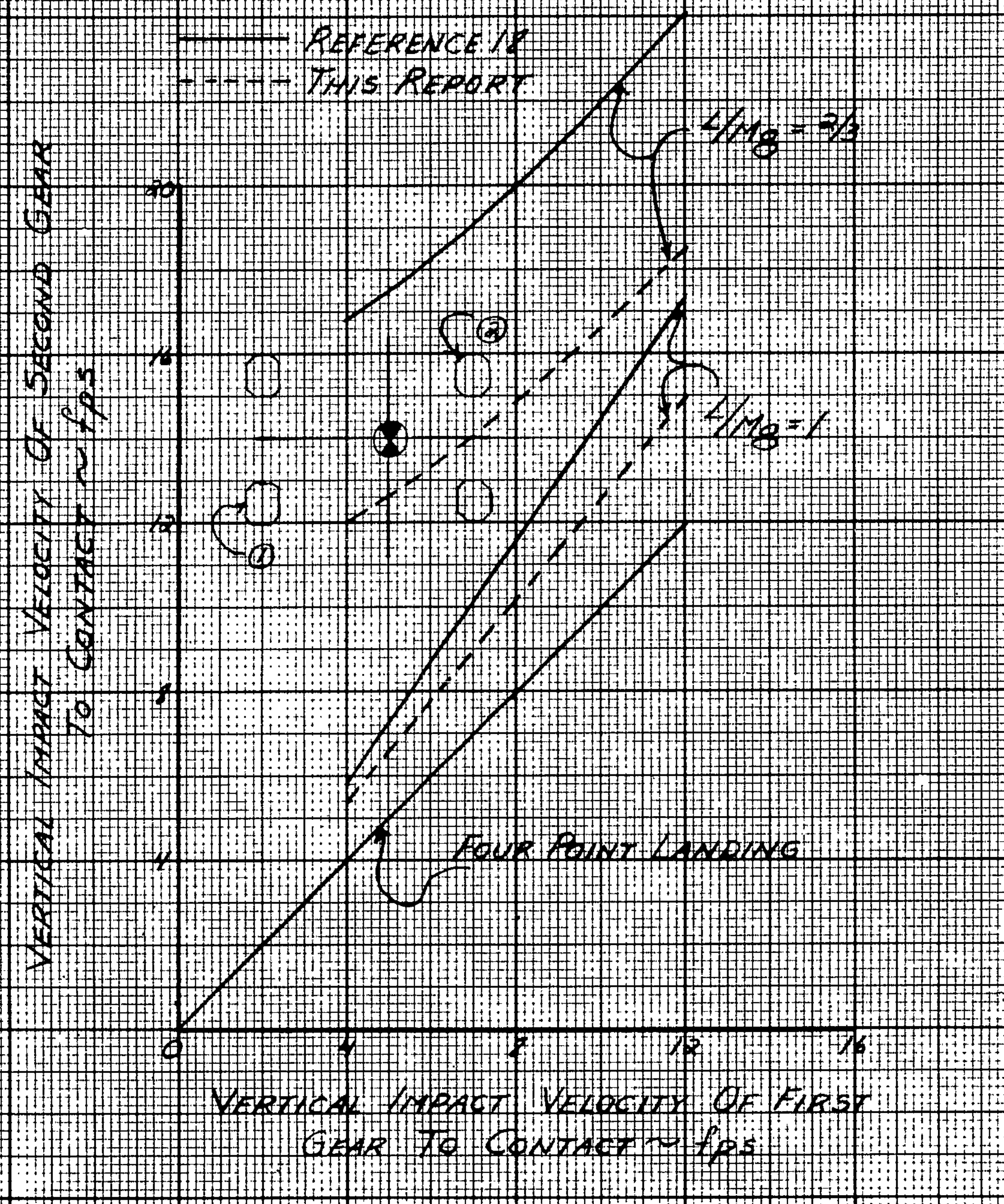


FIGURE 13 COMPARISON OF LANDING GEAR CONTACT VELOCITIES BETWEEN THIS REPORT AND THE IMPULSE MOMENTUM METHOD FOR SECOND IMPACT ON THE NOSE GEAR OF A QUADRICYCLE AIRPLANE.

fined as equivalent mass term includes the effect of all masses on the total kinetic energy arising from the velocity of the related coordinate. Whereas, dynamically coupled systems include the same kind of terms as the elastically coupled system with the addition of cross coupling terms arising from the part of the total kinetic energy due to the cross products of the velocities.

It can be seen that considerable difficulty can be encountered in trying to attach physical signifigance to equivalent mass terms as defined above. However, for the problems associated with landing gear design criteria, it appears that the effective mass acting on each landing gear unit must be defined in a much more restrictive sense. Actually the problem is to relate the dynamics of the airplane to that of the drop test. Hence, a coordinate transformation must be performed to decouple the coordinate associated with the landing gear unit in contact with the runway both elastically and dynamically. The mass term associated with this coordinate is the effective mass acting on that landing gear unit and can be directly associated with the drop test equation. Any set of original equations which cannot be so transformed cannot be directly related to the drop test equations and hence cannot have a true effective mass. It is to be noted also that the usual concept of kinetic energy in connection with landing gear design criteria can have physical signifigance only if calculated using a true effective mass.

Figures 10, 11, 12, and 13 show curves comparing the results obtained in this report and those shown in Reference 19. Good agreement was obtained for the case of full wing lift. Whereas, although the trends are the same, a difference in magnitude is shown for the case of two-thirds wing lift.

Effect of Parameter Changes

Certain problems exist in the use of the effective mass for determining landing load factors. For example, it is possible to locate the landing gear units so close together that it is not possible to obtain independent impacts on the landing gear units. In this case, the transaction of two or more landing gear units must be studied to determine the load factor that will be developed. Since no true effective mass can be determined for this case, it will be necessary to arrive at some compromise procedure. However, it is possible that the analysis in this case would be reasonable on the basis of the assumption that only one landing gear unit is in contact with the runway. This would retain the effective mass concept as outlined in this report, delegating considerable importance to the criterion used to determine the initial rate of descent.

The effect of lateral location of the main landing gear relative to the fore and aft centerline of the airplane is shown in Figure 14a. The corresponding study for the nose gear is shown in Figure 14b. Moving the landing gear unit away from the airplane centerline reduces the magnitude of the vertical force due to impact. This ef-

Table 1 Velocities & Forces for Various Parameter Combinations

Anal. No.	Init. Vel. LMG $\dot{Z}_{10}$	Vel. End Impact $\dot{Z}_{1t}/t$	Init. Vel. RMG $\dot{Z}_{20}/t$	$\dot{Z}_{20}/\dot{Z}_{10}$	Max Force LMG V_{1Max}/t X 10 -3	Max Force RMG V_{2Max}/t X 10 -3	V_{2Max}/V_{1Max}	Time of Free Flt. t_{ff}	Comments
104	144	-108.5/.359	174.6/.374	1.213	72.6/.149	88.1/.523	1.213	.016	C-119 B Full Lift,
105	96	- 72.4/.359	116.4/.549	1.213	48.4/.149	58.7/.698	1.213	.190	$\bar{Z}_3$ = - 72.0
106	48	- 36.2/.359	58.2/1.070	1.213	24.2/.142	29.4/1.219	1.213	.712	
108	144	-103.5/.386	231.0/.397	1.604	80.0/.160	124. /.553	1.550	.011	C-119 B 2/3 Lift,
109	96	- 67.1/.400	188.6/.516	1.967	56.0/.116	102.5/.674	1.830	.116	$\bar{Z}_3$ = - 75.7
110	48	- 30.0/.444	156.4/.714	3.260	32.4/.184	86.3/.874	2.670	.270	
111	144	-105.3/.324	214 /.398	1.486	65.0/.132	124.3/.572	1.913	.074	C-119 B Full Lift,
112	96	- 70.2/.324	142.9/.574	1.486	43.3/.132	82.9/.748	1.913	.250	s = 0.6, $\bar{Z}_3$ = - 75.7
113	48	- 35.1/.324	71.4/1.104	1.486	21.7/.132	41.4/1.278	1.913	.780	
114	144	-112.2/.408	109.8/.635	.763	83.5/.174	49.6/.767	.593	.227	C-119 B Full Lift,
115	96	- 74.8/.408	73.2/.980	.763	55.7/.174	33.0/1.112	.593	.572	s = - 0.6
116	48	- 37.4/.408	36.6/2.014	.763	27.9/.174	16.5/2.146	.593	1.606	
117	144	-103.5/.307	232 /.375	1.610	61.2/.123	98.6/.498	1.610	.068	C-119 B Full Lift,
118	96	- 69.0/.307	154.7/.538	1.610	40.8/.123	65.7/.661	1.610	.231	l_1 = - 225, l_2 = 225
119	48	- 34.5/.307	77.3/1.028	1.610	20.4/.123	32.9/1.151	1.610	.721	
184	144	- 98.6/.328	288.7/.336	2.005	66.4/.132	127.8/.464	1.925	.008	C-119 B 2/3 Lift,
185	96	- 63.9/.339	224.8/.438	2.340	46.1/.136	100.7/.567	2.182	.099	l_1 = - 225, l_2 = 225
186	48	- 28.7/.372	172.7/.624	3.600	26.1/.149	78.6/.754	3.010	.252	
120	144	-108.5/.359	* 66.8/.514	.464	72.6/.149	38.0/.679	.524	.155	C-119 B Full Lift,
121	96	- 72.4/.359	* 44.5/.864	.464	48.4/.149	24.9/1.018	.514	.505	$\bar{Z}_2$ = - 160, $\bar{Z}_3$ = - 46.8
122	48	- 36.2/.359	* 22.3/1.915	.464	24.2/.149	12.7/2.080	.524	1.556	

Table 1 (Cont'd)

Anal. No.	$\dot{z}_{10}$	$\dot{z}_{1t}/t$	$\dot{z}_{20}/t$	$\dot{z}_{20}/\dot{z}_{10}$	V_{1Max}/t X 10^{-3}	V_{2Max}/t X 10^{-3}	V_{2Max}/V_{1Max}	t_{ff}	
123	144	-103.5/.386	*103.5/.396	.719	80.0/.161	68.0/.580	.857	.010	C-119 B 2/3 Lift,
124	96	- 67.1/.400	* 99.3/.540	1.037	56.0/.167	65.6/.724	1.172	.140	$\bar{z}_2$ = - 160, $\bar{z}_3$ = - 46.8
125	48	- 30.0/.444	* 99.6/.729	2.080	32.4/.184	65.8/.913	2.030	.285	
129	161.5	-121.7/.359	160.8/.504	.995	81.5/.149	81.1/.653	.995	.145	C-119 B Full Lift,
130	113.5	- 85.5/.359	102.6/.775	.905	57.3/.149	51.8/.924	.905	.416	$-_o$ = - 0.1, $\bar{z}_2$ = - 75.7
131	65.5	- 49.4/.359	44.4/1.753	.678	33.0/.149	22.4/1.902	.678	1.394	$\bar{z}_3$ = - 72.0
126	144	-104.7/.414	*114.2/1.426	.793	172.4/.175	74.1/1.608	.430	1.012	C-119 B 2/3 Lift,
127	96	- 67.8/.431	*119.5/1.391	1 .245	121.1/.182	77.0/1.571	.635	.960	K = 10,000, C = 200
128	48	- 30.3/.479	30.3/.949	.632	70.7/.201	53.5/1.171	.757	.470	L_2 = + 1, L_1 = - 1
146	144	-111.6/.540	* 92.5/1.094	.635	117.0/.237	61.8/1.280	.528	.554	C-119 B 2/3 Lift,
147	96	- 72.2/.565	*105.6/1.185	.110	83.4 /.248	77.5/1.395	.929	.620	L_1 = - 72.0, L_2 = 72.0
									$\bar{z}_2$ = - 75.7, $\bar{z}_3$ = - 72.0
157	144	- 60.4/.371	167.9/.468	1.166	65.7/.091	76.6/.559	1.166	.097	
158	96	- 40.3/.370	111.9/.692	1.166	43.8/.091	51.1/.783	1.167	.322	C-119 B Full Lift, C=300
159	48	- 20.1/.370	56.0/1.369	1.166	21.9/.091	25.5/1.460	1.164	.999	$\bar{z}_2$ = - 75.7, $\bar{z}_3$ = - 72.0
160	144	- 47.6/.414			70.8/.103	108.2/.512	1.528		C-119 B 2/3 Lift, C = 300
161	96	- 26.2/.440	184.3/.521	1.920	49.1/.109	89.2/.621	1.817	.081	$\bar{z}_2$ = - 75.7, $\bar{z}_3$ = - 72.0
162	48				28.9/.128	76.8/.852	2.657		
163	144	-143.1/.358	179.4/.458	1.246	81.6/.178	98.5/.608	1.207	.100	C-119 B Full Lift, C = 1,
164	96	- 95.4/.358	119.6/.669	1.246	54.4/.178	65.6/.819	1.206	.311	$\bar{z}_2$ = - 75.7, $\bar{z}_3$ = - 72.0
165	48	- 47.7/.358	59.8/1.302	1.246	27.2/.178	3.4/1.480	.125	.944	
166	144	-141.8/.330	234.9/.348	1.631	89.6/.139	141.7/.534	1.581	.018	C-119 B 2/3 Lift, C = 1,
167	96	- 95.3/.392	191.9/.513	1.999	63.3/.196	117.4/.700	1.855	.121	$\bar{z}_2$ = - 75.7, $\bar{z}_3$ = - 72.0
168	48	- 47.6/.425	157.9/.709	3.289	36.8/.212	59.7/.865	1.622	.284	
154	144	- 73.4/.578	170.3/.618	1.183	42.2/.173	49.9/.791	1.182	.040	C-119 B Full Lift,
155	96	- 48.9/.578	113.6/.911	1.183	28.1/.173	33.3/1.084	1.185	.333	K = 2000, C = 150,
156	48	- 24.5/.578	56.8/1.788	1.183	14.1/.172	16.7/1.960	1.184	1.210	$\bar{z}_2$ = - 100, $\bar{z}_3$ = - 72

Table 1 (Cont'd)

Anal. No.	$\dot{Z}_{10}$	$\dot{Z}_{1t}/t$	$\dot{Z}_{20}/t$	$\dot{Z}_{20}/\dot{Z}_{10}$	V_{1Max}/t X 10^{-3}	V_{1Max}/t X 10^{-3}	V_{2Max}/V_{1Max}	t_{ff}	
181	144	- 55.3/.674			48.3/.203	81.8/.824	1.694		C-119 B 2/3 Lift
182	96	- 28.1/.734			34.5/.218	69.5/.927	2.014		$\underline{K}$ = 2000, C $\equiv$ 150
183	48				21.2/.263	61.8/1.146	2.915		Z_2 = - 100, Z_3 = - 72
136	144	-108.5/.359	*208.4/.654	1.447	72.6/.149	89.7/.776	1.236	.295	XC-120 Full Lift
137	96	- 72.3/.359	*138.9/.958	1.447	48.4/.149	59.8/1.080	1.236	.599	
138	48	- 36.2/.359	* 69.5/1.871	1.447	24.2/.149	29.9/1.993	1.236	1.512	
139	144	-103.5/.386	*289.4/.545	2.010	80.0/.161	129.6/.671	1.620	.159	XC-120 2/3 Lift
140	96	- 67.1/.400	*239.7/.696	2.497	56.0/.167	108.2/.823	1.932	.296	
141	48	- 30.0/.444	202.2/.937	4.212	32.4/.184			.493	
169	144	-125.2/.960	*		246.2/.442	83.3/1.197	.338		B-36 Full Lift
170	96	- 83.5/.960	* 56.8/1.406	.592	164.1/.442	55.6/1.643	.339	.446	
171	48	- 41.7/.960	* 28.4/3.168	.592	82.1/.442	27.8/3.405	.339	2.208	
172	144	-117.3/1.141	*		321.6/.525	213.7/1.396	.664		B-36 2/3 Lift
173	96	- 74.6/1.228	*		244.0/.564	194.4/1.485	.797		
174	48	- 28.5/1.458	*		173.2/.659	189.2/1.716	1.092		
175	144	- 91.0/.231	* 71.6/.299	.497	43.7/.085	12.8/.339	.293	.068	F-84 Full Lift
176	96	- 60.7/.231	* 47.7/.508	.497	29.1/.085	8.6/.548	.296	.177	
177	48	- 30.3/.231	* 23.9/1.137	.498	14.6/.085	4.3/1.177	.294	.906	
178	144	- 86.4/.244	* 93.0/.257	.646	46.4/.090	17.5/.300	.377	.013	F-84 2/3 Lift
179	96	- 55.8/.2502	* 84.0/.3746	.875	31.9/.092	15.9/.4176	.498	.1244	
180	48	- 24.9/.271	* 81.1/.545	1.690	17.4/.100	15.4/.588	.885	.274	
135	30.8	- 14.1/.368	16.5/1.367	.536	4.98/.111	2.7/1.478	.542	.999	C-47 Full Lift

* Second Impact Occurs on Nose Gear

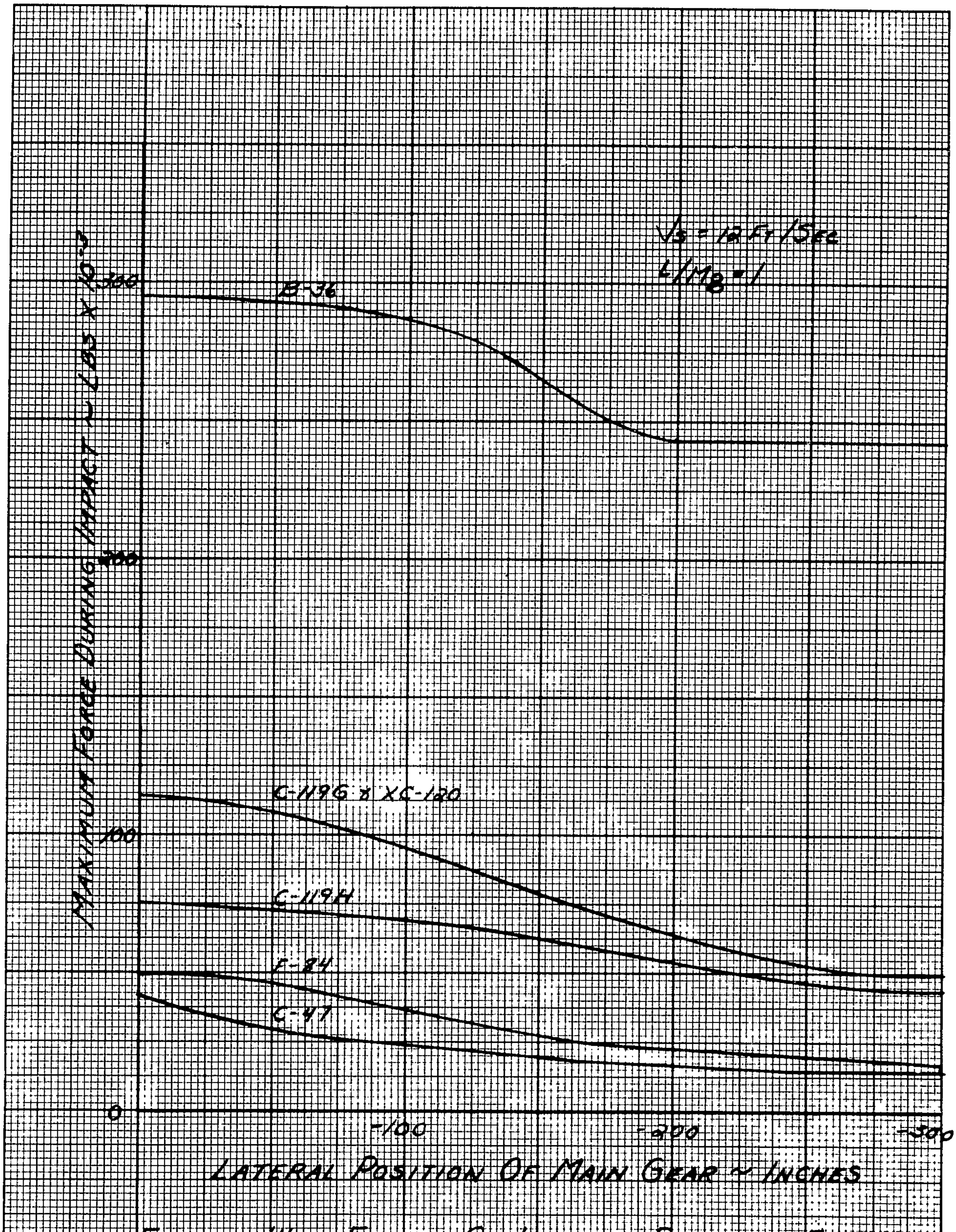


FIGURE 14a EFFECT OF LATERAL POSITION OF MAIN GEAR ON MAXIMUM IMPACT FORCE

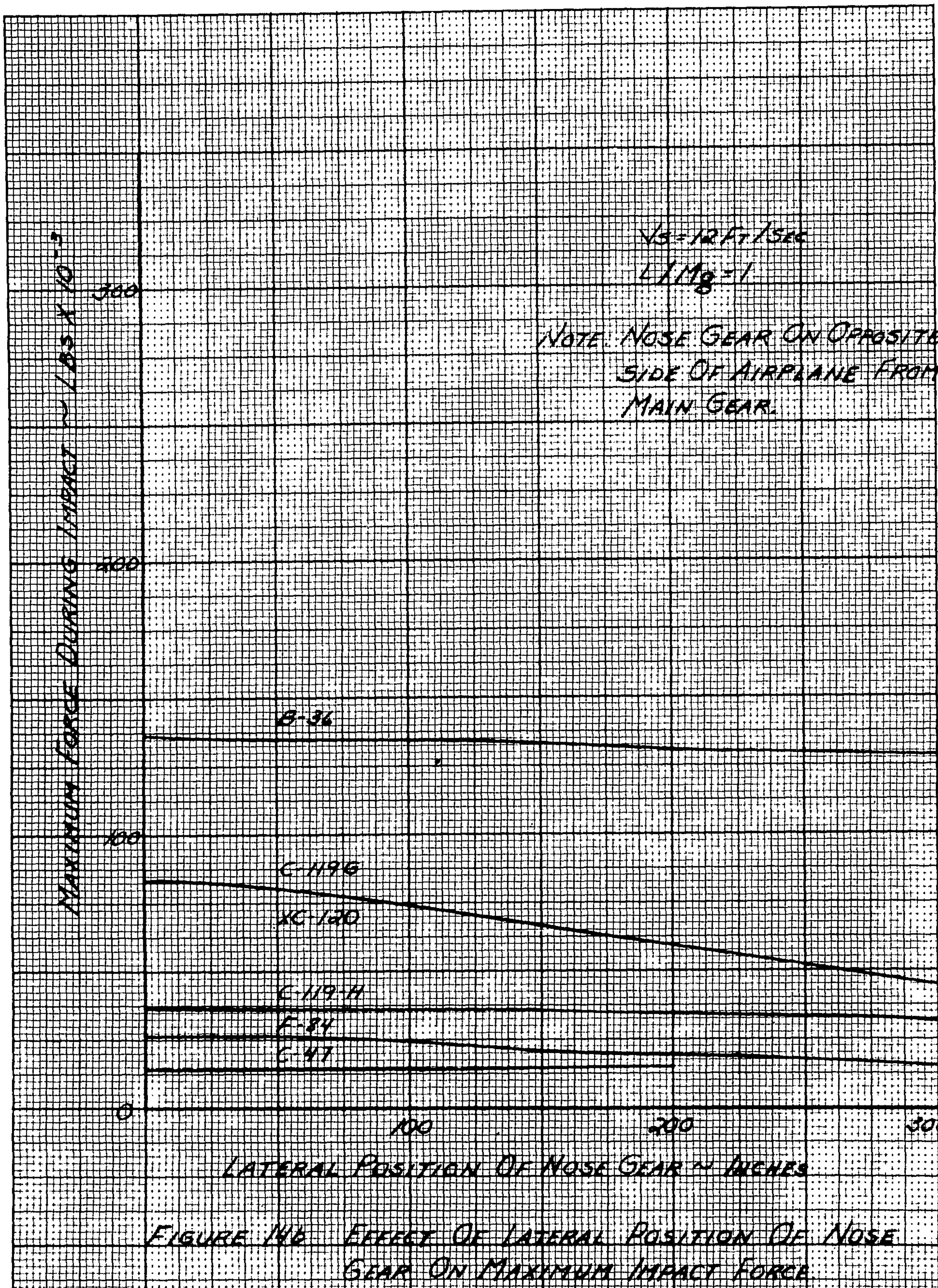


FIGURE 14b EFFECT OF LATERAL POSITION OF NOSE GEAR ON MAXIMUM IMPACT FORCE

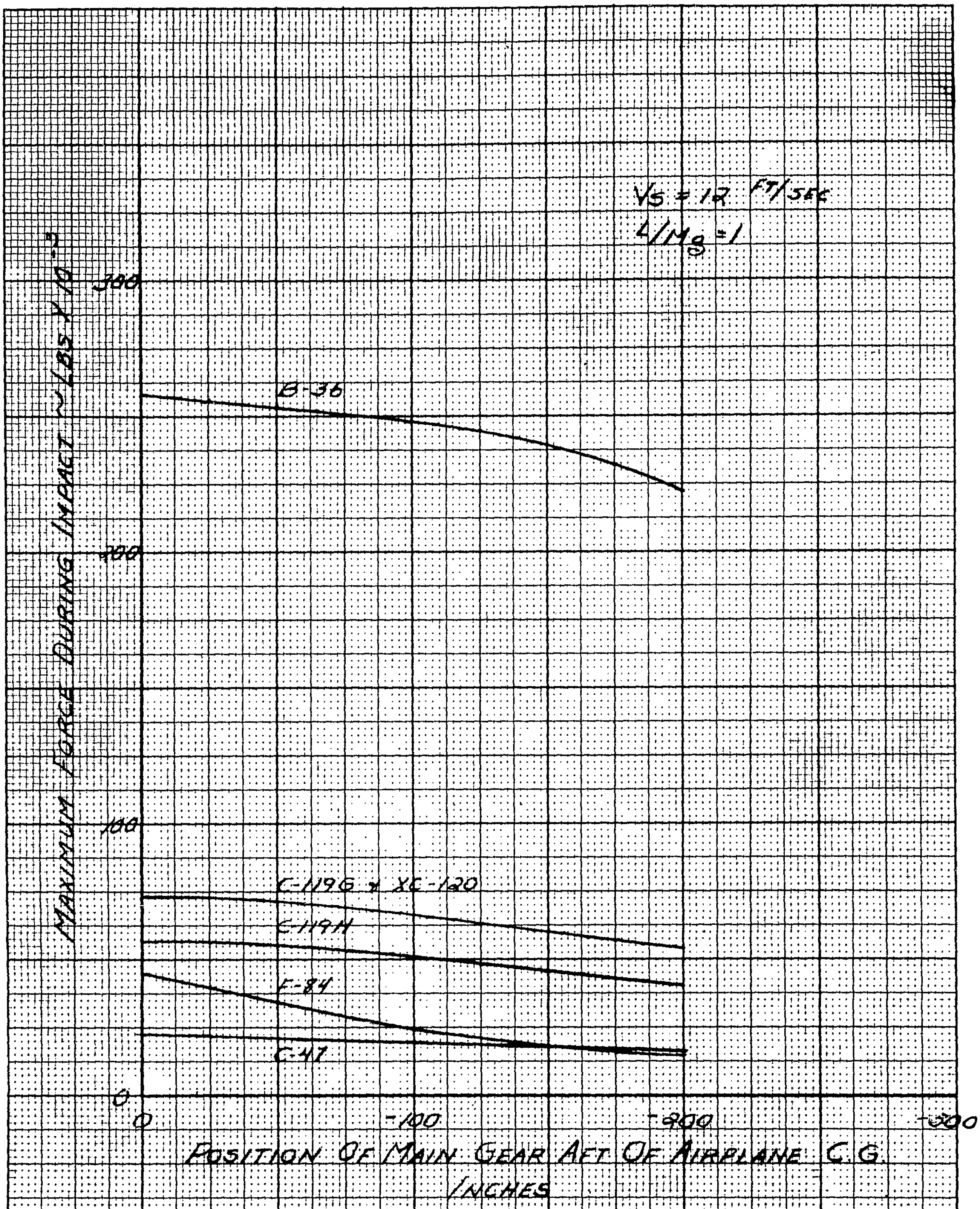


FIGURE 15a EFFECT OF AFT POSITION OF MAIN GEAR RELATIVE TO THE AIRPLANE C.G. ON THE MAXIMUM IMPACT FORCE

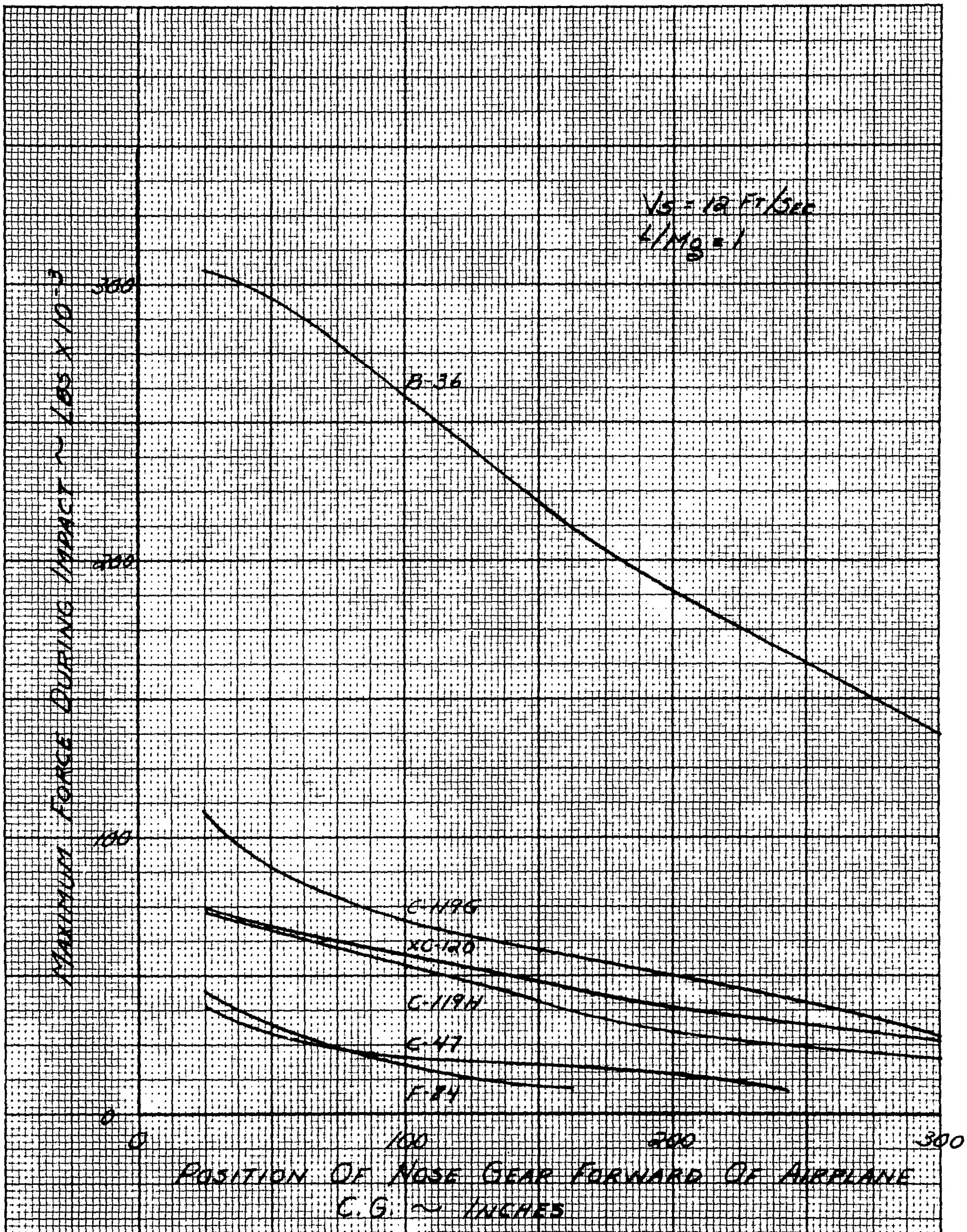


FIGURE 15b EFFECT OF FORWARD POSITION OF NOSE GEAR RELATIVE TO THE AIRPLANE C.G. ON THE MAXIMUM IMPACT FORCE

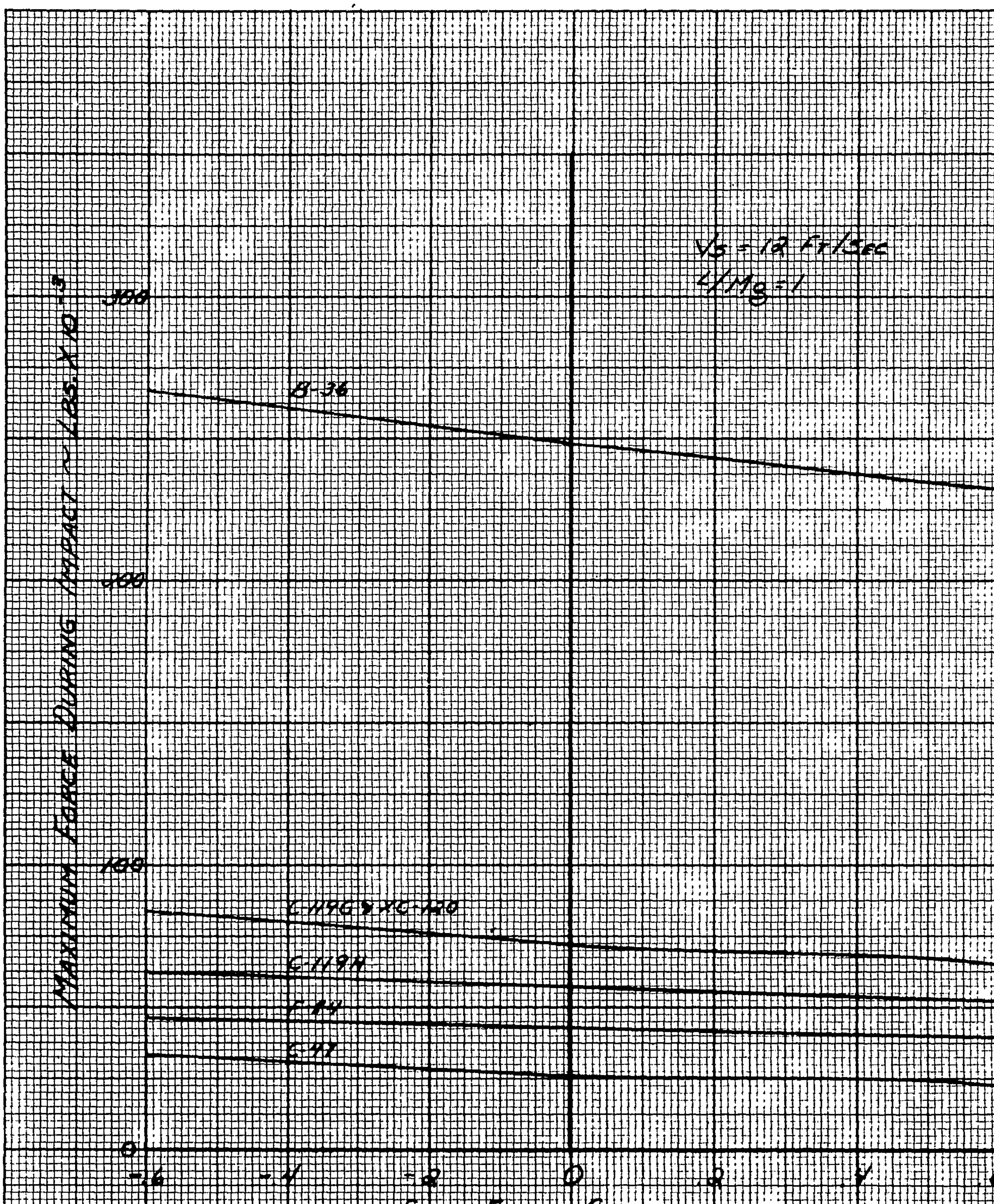


FIGURE 18a EFFECT OF SIDE FORCE COEFFICIENT ON MAXIMUM IMPACT FORCE FOR MAIN GEAR

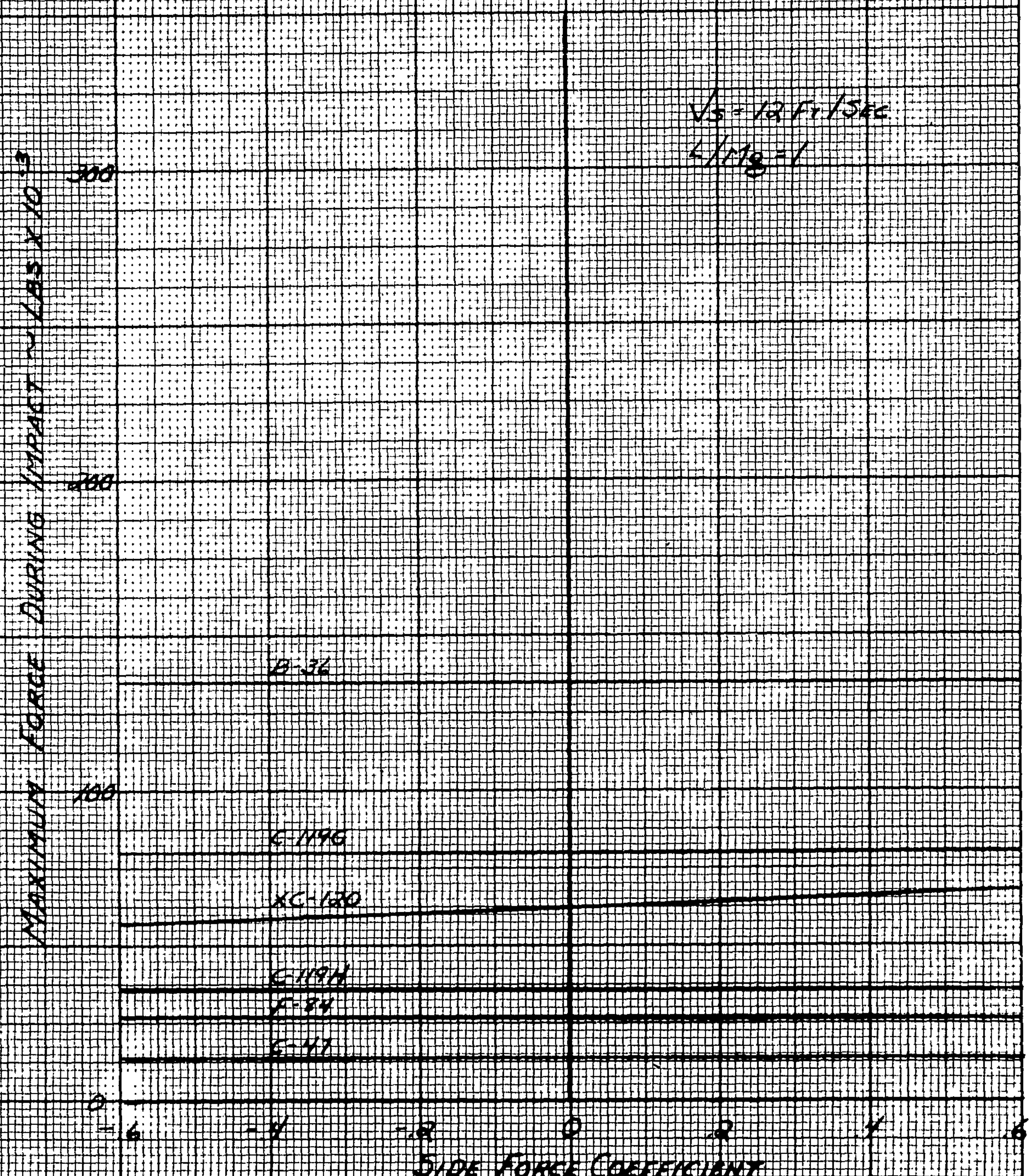


FIGURE 16b. EFFECT OF SIDE FORCE COEFFICIENT ON MAXIMUM IMPACT FORCE FOR NOSE GEAR.

fect is more pronounced for main gear than for the nose gear. It is noted that the rate of descent has been held constant at 12 ft/sec in this study. Hence, the effect of geometry on the initial rate of descent must be taken into account to obtain the optimum landing gear configuration.

Figures 15a and 15b show the change in vertical reaction due to fore and aft locations of the main and nose gears relative to the airplane center of gravity. Both gears show a reduction in force due to being moved farther from the center of gravity. This effect is more pronounced for the nose gear.

The influence of side force on the vertical reaction is shown in Figures 16a and 16b for the nose and main gears of the six airplanes studied in this report. It appears that this parameter is of lesser importance than the geometrical parameters after the initial rate of descent has been established. In fact, locating the nose gear on the centerline of the airplane nullifies entirely the effect of side force on the vertical reaction.

Discussion of Landing Gear Design Problem

It has been established by calculations that the second impact is somewhat more severe than the first. Therefore, the criteria for designing landing gears necessarily must consist of two phases. The first phase is the determination of the magnitude of the second impact relative to the first impact, taking into account the geometry of the airplane, inertia, and so-called external forces. The second phase consists of determining the magnitude of the second impact on the basis of these same parameters, but determined by some pre-established criteria for the maximum impact and rate of descent. Using the derivations shown in this report both phases can be analyzed. Hence, although calculations are shown in this report giving the relative severity between the first and subsequent impacts, no attempt is made to establish the magnitude of the initial velocity criterion.

For landing gear design, it is essential that the maximum load factor that will be imposed upon that landing gear unit be determined regardless of its sequential relationship in the landing maneuver. However, the data presented in this report shows the need for considering the second impact in the criteria. It is pointed out that the basic concept of effective mass and initial velocity should be retained.

Suppose a side force of .6 times the vertical reaction acts on the landing gear in a manner to produce acceleration toward the next gear to contact. This gives a second impact almost twice as large as the first. Consequently, a mass criterion must be arrived at for the design of landing gear regardless of which impact is involved. Having arrived at that, the geometry of the airplane can be considered in arriving at an actual magnitude for a given velocity criterion. Of course, it appears that this velocity criterion should

be controlled somewhat by the geometry, inertia, and external forces applied to the airplane.

Several curves designed to show the comparison between our calculated results and those of Reference 18 show reasonable agreement in most categories. Although the methods of Reference 18 appear to give a reasonable approximation of velocity at contact for the second landing impact, these methods do not allow consideration of the landing gear characteristics, such as length of stroke. The analysis is based upon introduction of equations for which it is necessary to assume a landing gear efficiency. There is no direct check, in the early stages of design, for the computed results.

Analytical equations can be based upon a more rational approach to the problem, for example, by establishing characteristics of landing gears from statistical methods which permit the use of straight-forward dynamical equations. The only difficulties that arise are in the establishment of the damping characteristics from the drop test records.

Reference 18 gives a very ingenious approach to the second impact velocity whereas the definition of effective mass is not restricted to the degree as used in this report. In other words, it is not shown in Reference 18 that the effective mass derived is a mass associated with a single degree of freedom system.

Calculations based upon derivations of the effective mass and vertical force have been made to obtain plots of various airplane parameters versus the vertical force for six different airplanes, namely the C-119-H, C-47, F-84, B-36, C-119-G, and XC-120 airplanes. To obtain these plots, the parameters associated with each airplane have been fixed for each curve, including an initial rate of descent of twelve feet per second. Then for each airplane, an analysis has been made for a main gear and a nose gear for which variations in l, r, and μ_s have been calculated. In each analysis it has been assumed that the side load is equal to 55% of the vertical load and lasts for a duration of .05 seconds. Combined plots are shown for these parameters against the vertical forces generated in Figures 14, 15, and 16.

Several calculations have been made carrying the results to the third impact. For the configurations tested, the third impact has always been less severe than the second. However, this does not mean that other airplane configurations might not have a more severe third impact, since the results of this report were obtained from the third impact on the nose gear. This impact is usually less severe than the second impact for the tricycle landing gear configuration.

The lateral position of the nose gear relative to the centerline of the airplane usually determines the magnitude of its impact. It appears in the case of the nose gear that the criteria should be based somewhat on the effect of pilot technique during the landing maneuver. It is to be noted that no landing test data have been obtained to date where the XC-120 airplane bounced from one main landing gear to the nose landing gear.

The magnitude of the landing gear design problem defies the use of one overall analytical solution. Hence, it is necessary to make rational assumptions in order to separate the problem into portions that can be handled in a practical manner. The logical separation in the landing gear problem consists of three principal parts: first, the inclusion of the whole airplane as a rigid body and the calculations of the landing gear forces based upon this assumption; second, the introduction of the consideration that these loads are based upon a magnification factor from the response of the airplane at resonance; and third, the study of the landing gear design characteristics and their effect on the airplane.

Considerable work is available in the literature on the effect of flexibility on airplane landing loads, whereas, very little has been done on the effect of the landing gear location. It remains to be determined, in the cases where failures have occurred, whether the flexibility of the airplane was at fault or whether the location of the landing gear was improper. In other words, the magnitudes of the loads on the landing gear depend upon the location of that landing gear on the airplane as well as the characteristics of flexibility of the airplane. However, it is to be noted that the design of each component part of the airplane must take into account the dynamical forces due to the oscillation of the airplane in its natural modes.

The data presented in this report show that where distinct impacts have been obtained, the second impact is always considerably greater than the first. As compared with a symmetrical landing with the same initial conditions, the first impact in an unsymmetrical landing is considerably lower than it would be if it were in a symmetrical landing, whereas the second impact is considerably higher than would be obtained in a symmetrical landing. In other words, the force generated in a symmetrical landing is approximately midway between the forces generated in the first and second impacts. It is pointed out that the second impact for symmetrical landings of tricycle landing gear type aircraft has been found to be less severe than the initial impact on the main landing gears. Again, considering a tricycle landing gear type airplane, the second impact will be more severe if the subsequent landing impact is on the second main landing gear.

SECTION III

PRESENTATION OF LANDING TEST DATA

Instrumentation

The Fairchild Airplane C-119-H was used for the series of landings conducted for this report. The airplane was instrumented so that its attitude could be established at all times during a landing. Accelerometers (a total of 17) were installed at various places in the aircraft to indicate the effects of landing gear impact throughout the airplane.

The left main gear was instrumented extensively by strain gages to show the forces acting on various parts of the gear during the landing. No strain gages were used on the nose gear, and only one gage for indicating side load was installed on the right main gear.

However, each landing gear unit was equipped with a rate of descent indicator, from which tire deflection can be obtained, and an oleo position indicator which recorded the deflection of each oleo during the landing.

Table 2 and Figures 17 through 24 contains a complete listing, along with location and description of each instrument.

Four Consolidated Engineering oscillographs were used to record the intelligence from the instruments through a total of 47 channels. The ground speed trace occurred on all four records and was used to orient the four oscillograph records obtained on each landing with respect to time.

C-119 H Instrumentation Table 2

Trace	Type of Instrumentation	Location	Used to Determine	Reference
1	Strain Gage	Left Main Gear Middle Main Post	Torsion in Main Post	Fig. 17, 22a, 22b
2	Strain Gage	Left Main Gear Axial Load in Oleo Strut	Axial Load in Oleo Strut	Fig. 17, 22a
3	Strain Gage	Left Main Gear Upper Main Post	Fore and Aft Bending in Main Post	Fig. 17, 22a
4	Strain Gage	Left Main Gear Outboard Axle	Vertical Load in Outboard Axle	Fig. 17
5	Strain Gage	Left Main Gear Inboard Axle	Vertical Load in Inboard Axle	Fig. 17
6	Strain Gage	Left Main Gear Outboard Axle	Drag Load in Outboard Axle	Fig. 17
7	Strain Gage	Left Main Gear Inboard Axle	Drag Load in Inboard Axle	Fig. 17
8	Wind Vane	Left Wing Tip	Airplane Angle of Yaw	Fig. 18
9	Strain Gage	Left Main Gear Lower Main Post	Axial Load in Main Post	Fig. 17, 22b
10	Strain Gage	Left Main Gear Upper Main Post	Side Bending in Main Post	Fig. 17, 22a
11	Strain Gage	Right Main Gear Upper Main Post	Side Bending in Main Post	Fig. 17, 22a
12	Strain Gage	Front of Fuel Wing Tank on Left Wing	Tension and Compression Load in Strut	Fig. 18
13	Strain Gage	Rear of Fuel Wing Tank on Left Wing	Tension and Compression Load in Strut	Fig. 18

C-119 H Instrumentation Table 2 (Cont'd)

Trace	Type of Instrumentation	Location	Used to Determine	Reference
14	Magnet and Induction Coil	Left Main Gear on Inboard Wheel	Rotational Speed of Wheel	Fig. 19
15	Angular Position Indicator	Left Rudder Torque Tube Near The Surface	Left Rudder Position	Fig. 20
16	Angular Position Indicator	Center (Spanwise) of Left Aileron	Left Aileron Position	Fig. 18
17	Angular Position Indicator	Left Elevator Push-Pull Tube	Elevator Position	Fig. 18
18	Angular Position Indicator	Spring Tab Push-Pull Tube. Stab. Sta. 142 Left	Elevator Spring Tab Position	Fig. 18
19	Angular Position Indicator	Left Main Gear Between Main Post & Swivel Arm	Angle Between Main Post and Swivel Arm	Fig. 17, 23a
20	Position Indicator	Nose Gear Oleo Strut	Oleo Strut Compression	Fig. 20, 23b
21	Position Indicator	Left Main Gear Oleo Strut	Oleo Strut Compression	Fig. 17, 21a
22	Position Indicator	Right Main Gear Oleo Strut	Oleo Strut Compression	Fig. 1 17, 21a
23	Position Indicator	Nose Gear Right Side of Wheel	Rate of Descent Tire Deflection	Fig. 19, 21b
24	Position Indicator	Left Main Gear Between Wheels	Rate of Descent Tire Deflection	Fig. 19,21a
25	Position Indicator	Right Main Gear Between Wheels	Rate of Descent Tire Deflection	Fig. 19, 21a
26	Gyro	Cargo Compartment At Left Side on Floor Fuselage Sta 330	Airplane Angle of Roll and Roll Velocity	Fig. 18, 20

C-119 H Instrumentation Table 2 (Cont'd)

Trace	Type of Instrumentation	Location	Used to Determine	Reference
27	Gyro	Cargo Compartment at Left Side on Floor Fuselage Sta 330	Airplane Angle of Pitch and Pitching Velocity	Fig. 18, 20
28	Accelerometer	Left Wing Tip Front Spar	Normal Acceleration	Fig. 18
29	Accelerometer	Left Wing Tip Rear Spar	Normal Acceleration	Fig. 18
30	Accelerometer	Left Wing Sta. 830 On Left Rear Spar	Normal Acceleration	Fig. 18
31	Accelerometer	Fuselage "C.G." 25% MAC Sta. 345 On Left Sidewall	Normal Acceleration	Fig. 18, 20
32	Accelerometer	Fuselage Nose Sta. 33 To Right Of Fuselage ℄	Normal Acceleration	Fig. 18, 20
33	Accelerometer	Stabilizer ℄ at Fuselage Sta. 995	Normal Acceleration	Fig. 18
34	Accelerometer	Left Wing Sta. 400 On Left Rear Spar	Normal Acceleration	Fig. 18
35	Accelerometer	Left Nacelle on Front Wall of Left Main Gear Well	Normal Acceleration	Fig. 19, 23c
36	Accelerometer	Right Wing Tip Front Spar	Normal Acceleration	Fig. 18
37	Accelerometer	Left Boom At Fuselage Sta. 953 Near ℄ of Boom	Lateral Acceleration	Fig. 18, 20
38	Accelerometer	Left Boom At Fuselage Sta. 953 Near ℄ Of Boom	Normal Acceleration	Fig. 18, 20
39	Accelerometer	Right Boom At Fuselage Sta. 953 Near ℄ of Boom	Normal Acceleration	Fig. 18, 20

C-119 H Instrumentation Table 2 (Cont'd)

Trace	Type of Instrumentation	Location	Used To Determine	Reference
40	Accelerometer	Left Fin Tip At Fuselage Sta. 998 and Fin Sta. 152	Lateral Acceleration	Fig. 20
41	Accelerometer	Left Wing Fuel Tank 12" From Tank Nose	Normal Acceleration	Fig. 18
42	Accelerometer	Left Wing Fuel Tank 11" From Nose	Lateral Acceleration	Fig. 18
43	Accelerometer	Left Wing Fuel Tank 15" From Rear Tip	Lateral Acceleration	Fig. 18
44	Accelerometer	Left Wing Fuel Tank 16" From Rear Tip	Normal Acceleration	Fig. 18

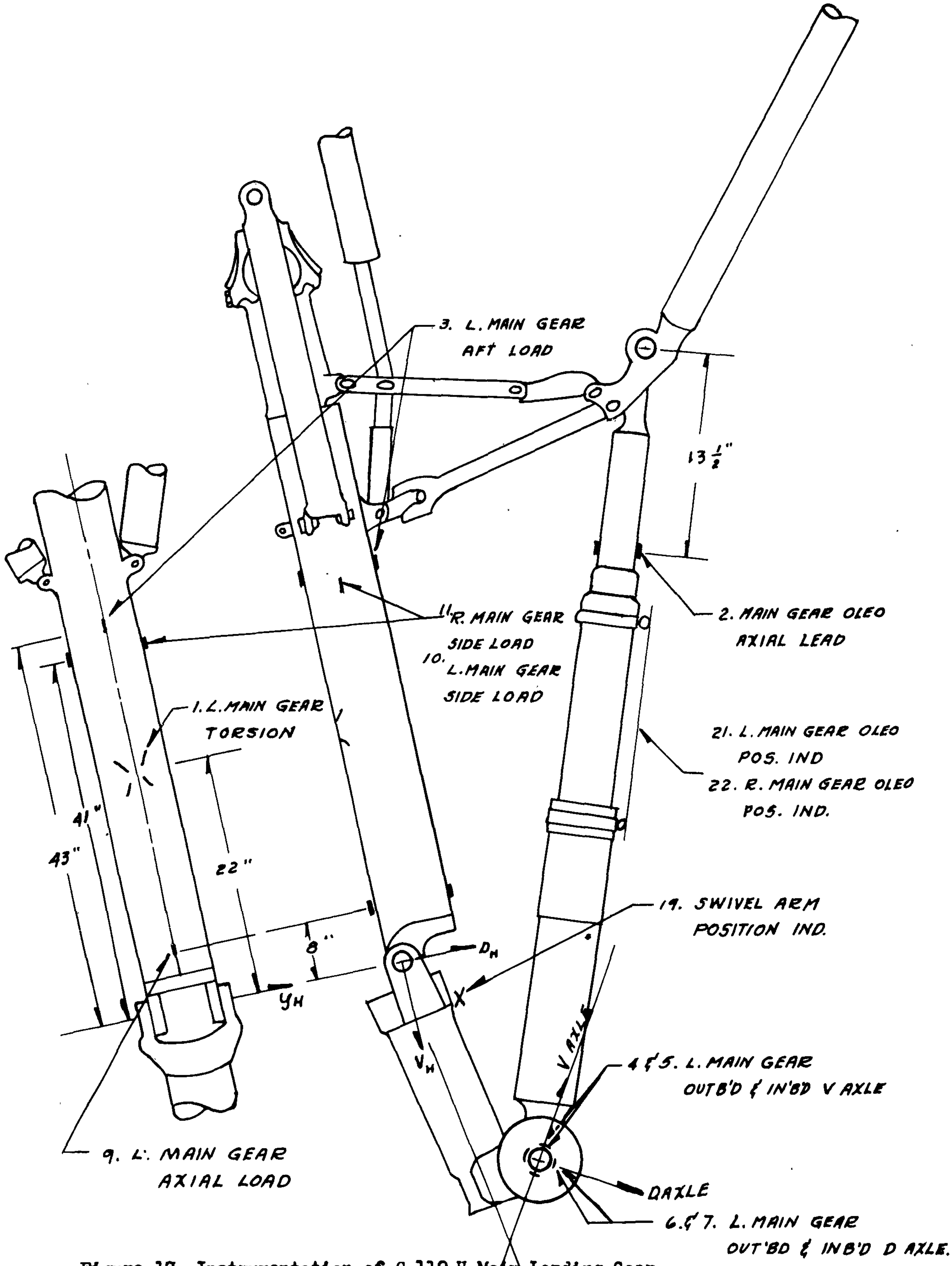
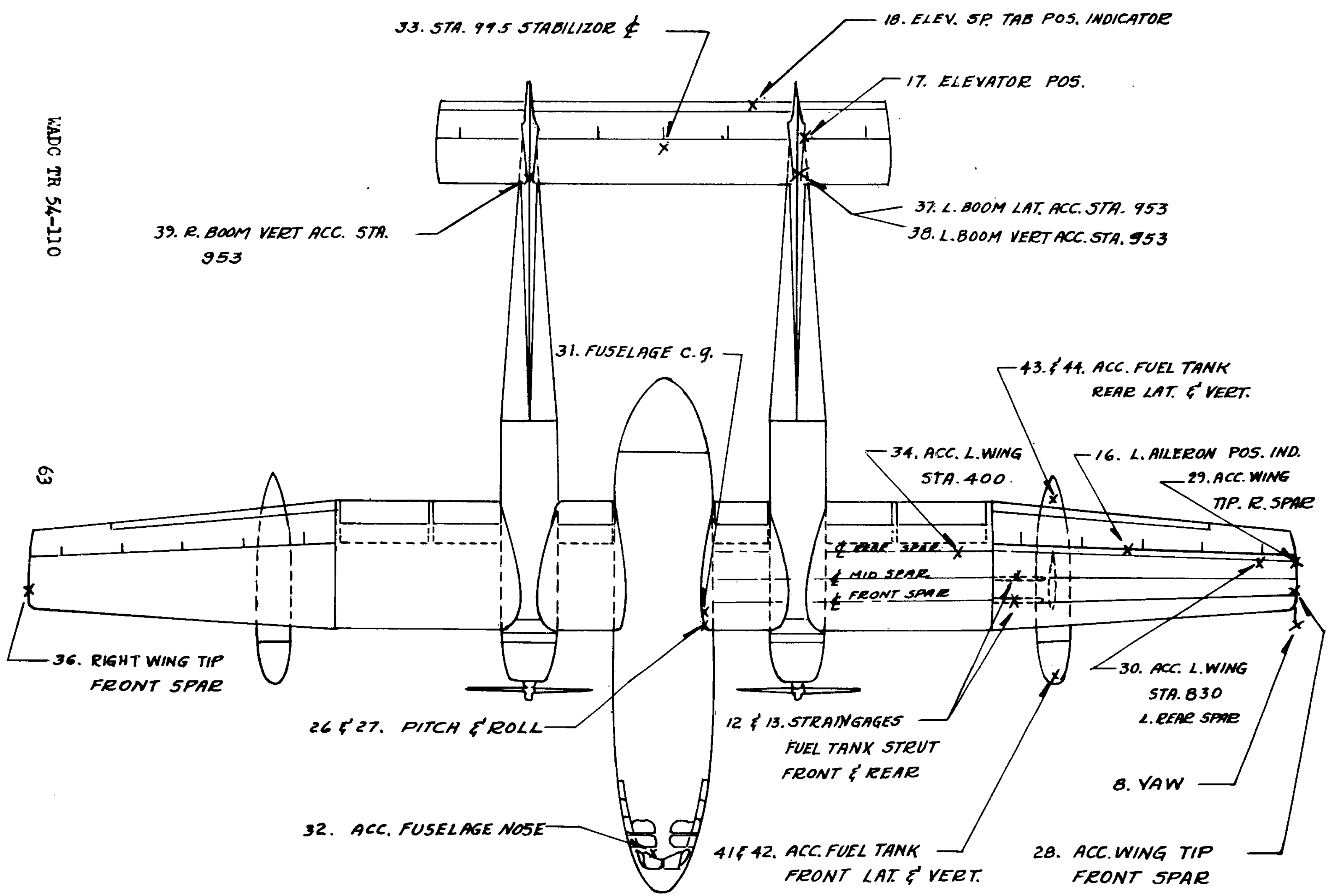
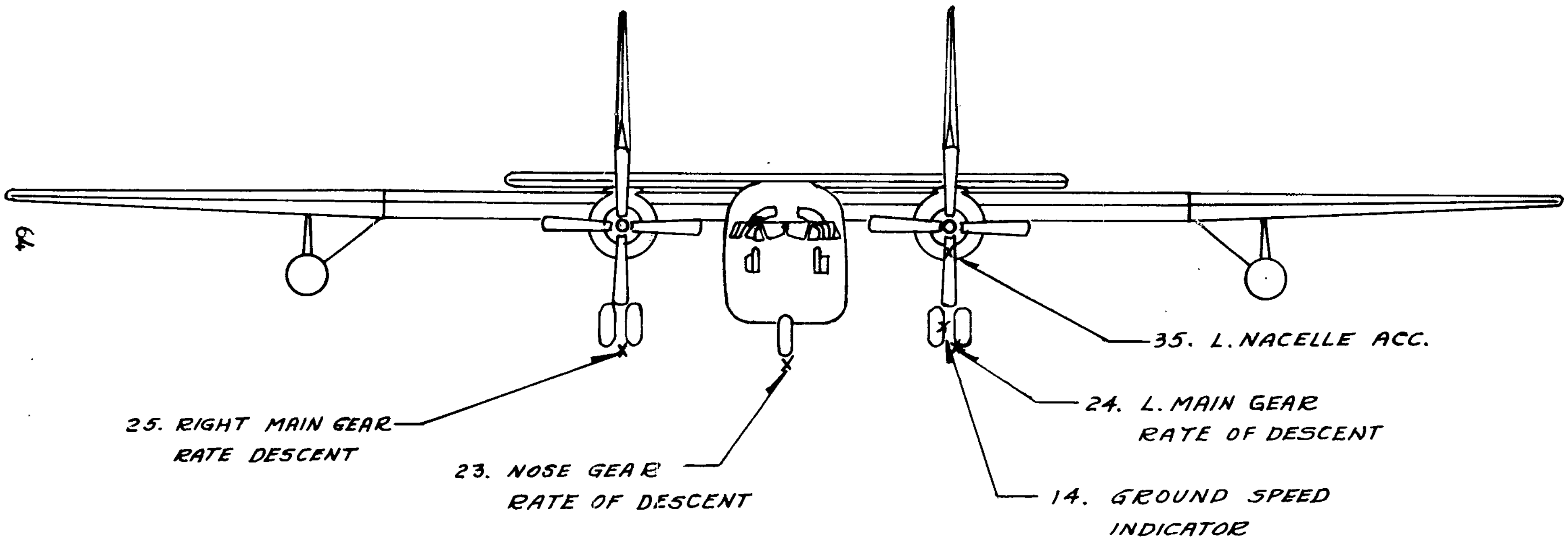


Figure 17 Instrumentation of C-119 H Main Landing-Gear



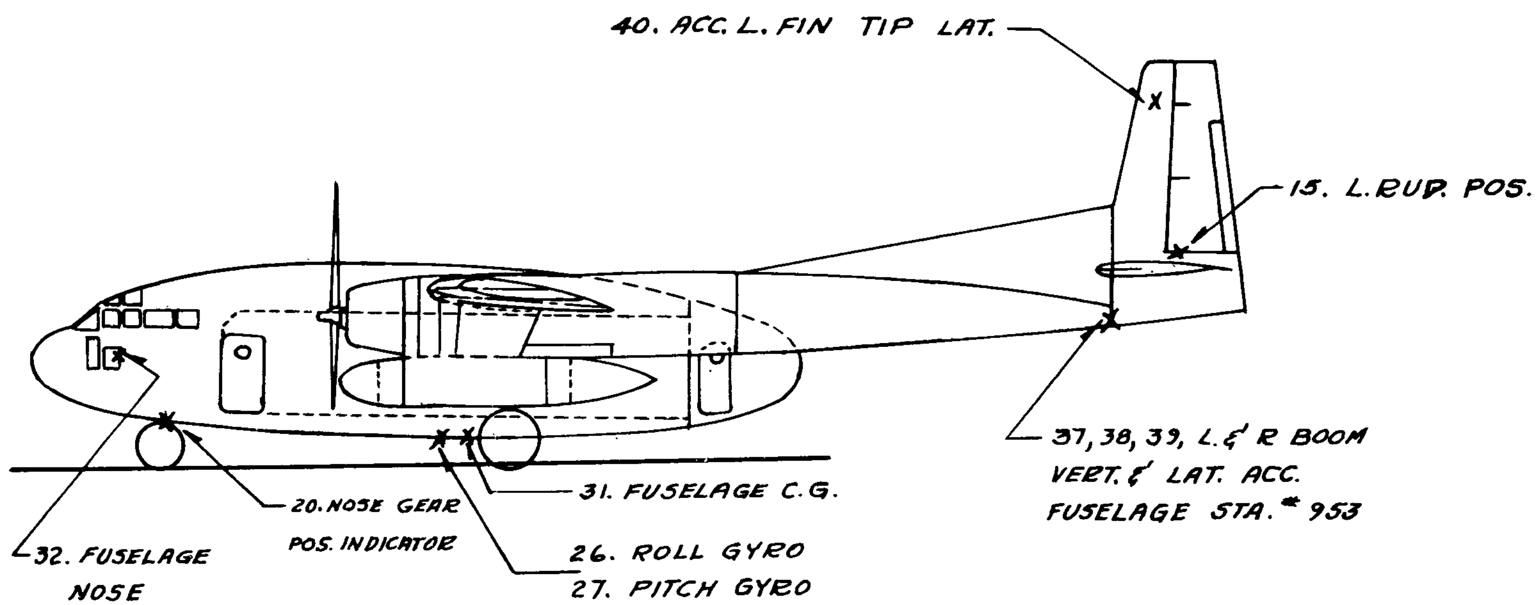
Instrumentation of C-119 H Airplane (Top View)

FIGURE 18



Instrumentation of C-119 H Airplane (Front View)

FIGURE 19



Instrumentation of C-119 H Airplane (Side View)

FIGURE 20

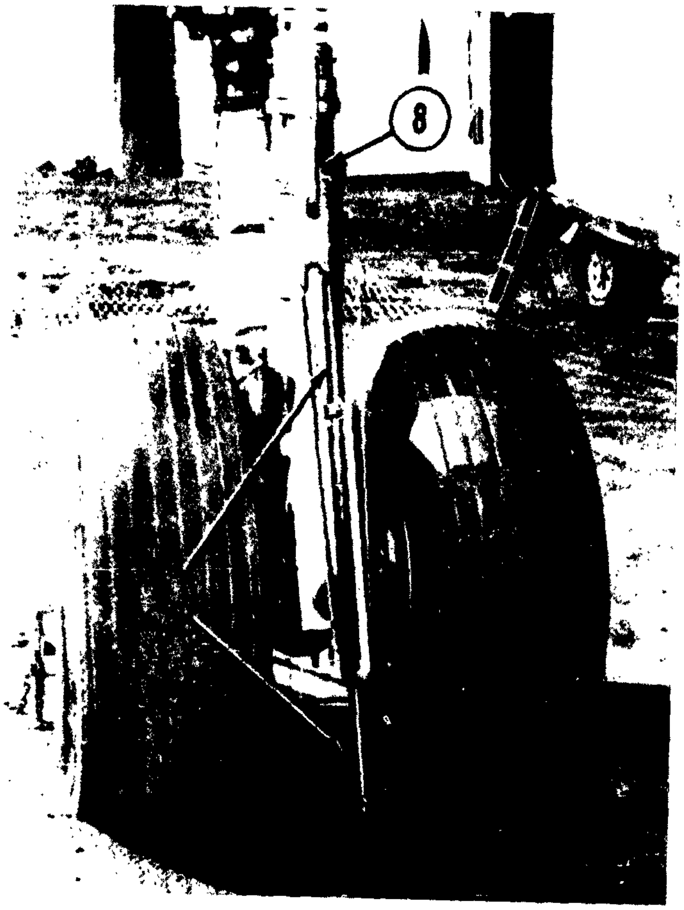


FIGURE 21a
Main landing gear rate of descent indicator, 7, and shock strut position indicator, 8.

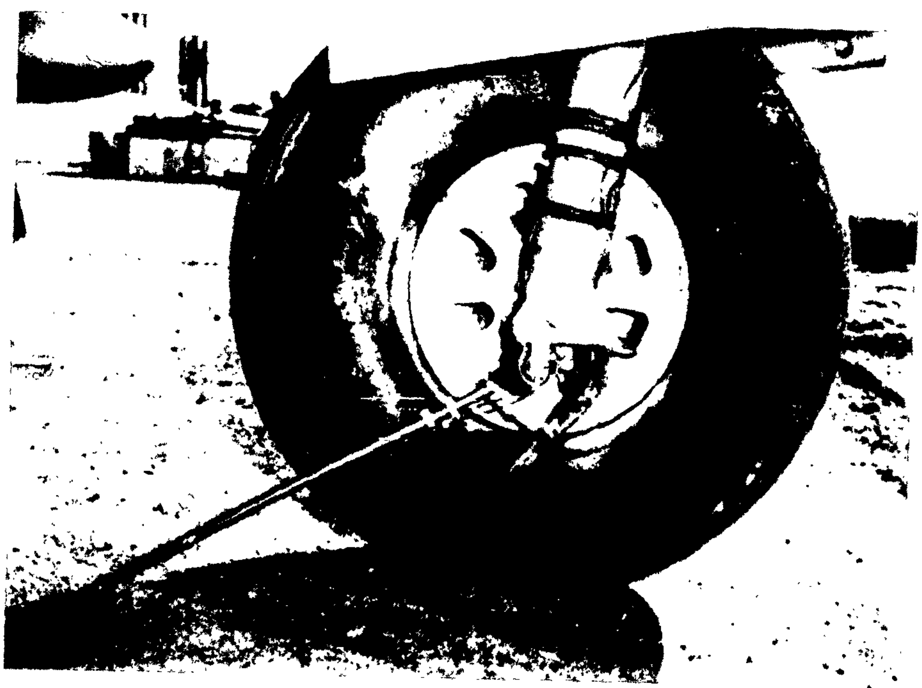


FIGURE 21b Nose gear rate of descent indicator.

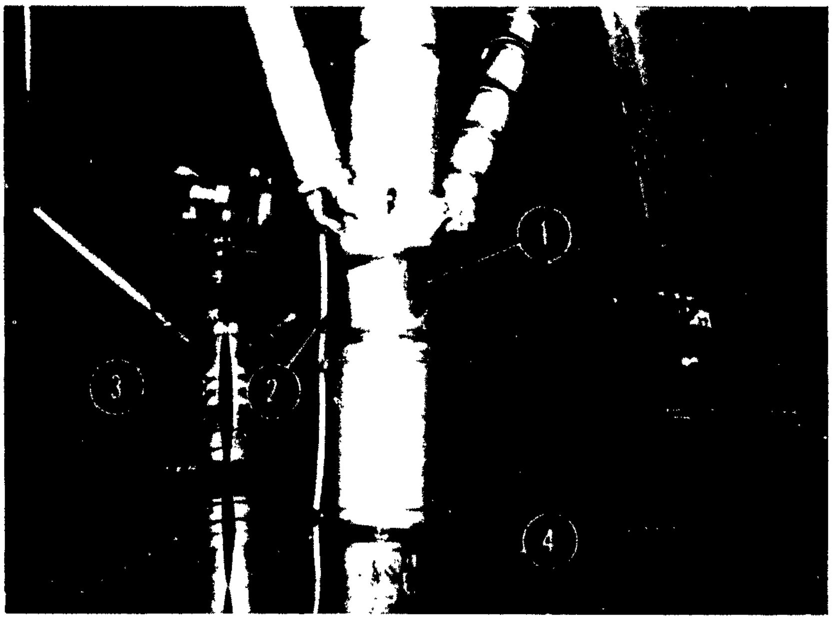


FIGURE 22a Strain gages located on upper left landing gear main post and shock strut: Fore and aft bending load, 1, side bending load, 2, shock strut axial load, 3, and torsion load, 4.

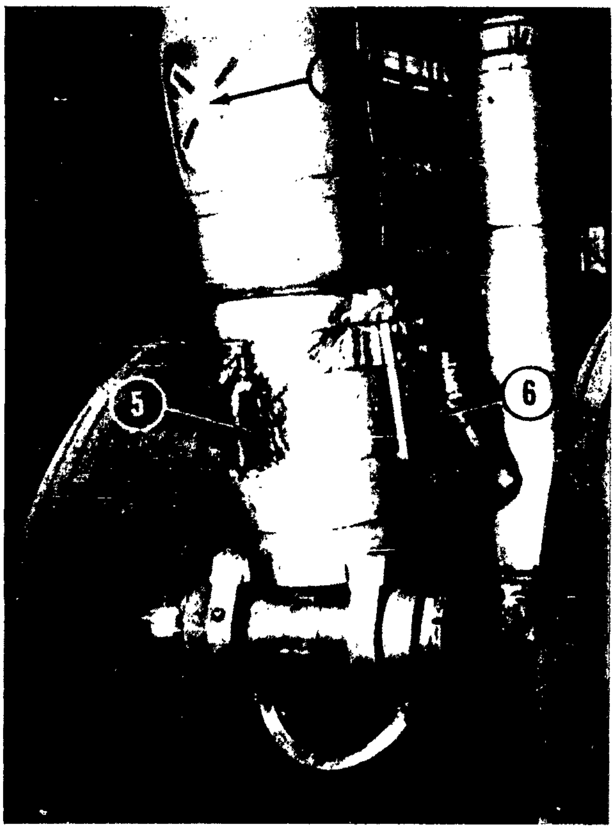


FIGURE 22b Strain gages located on lower left main post: Torsion load, 4, axial load, 5, and compensating gages, 6.

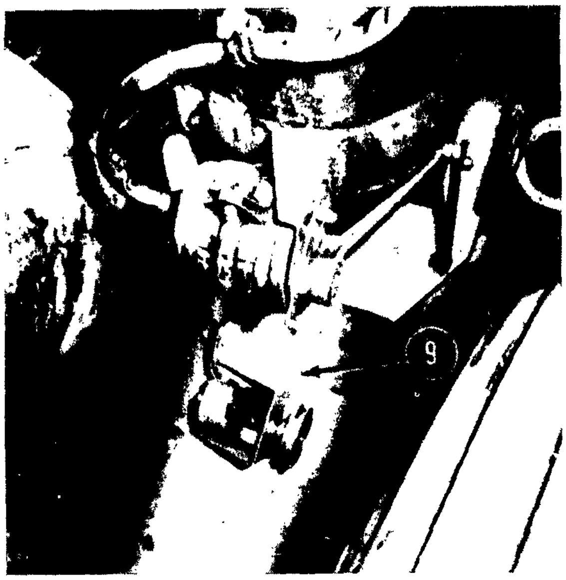


FIGURE 23a
Main landing gear lever position indicator (helipot and cable type), 9.

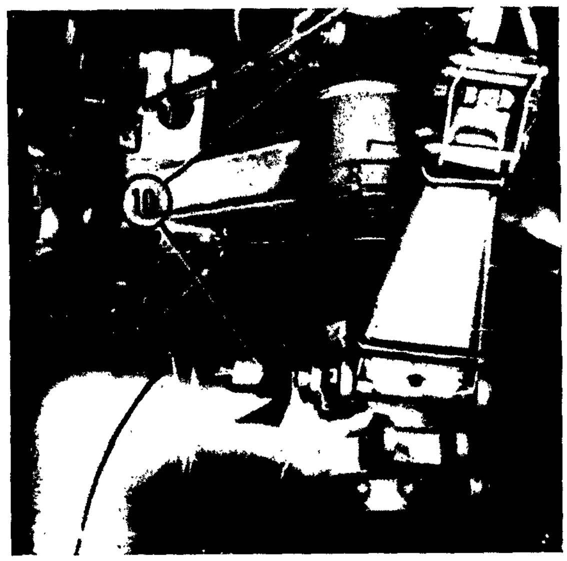


FIGURE 23b
Nose gear shock strut position indicator (helipot and cable type), 10.

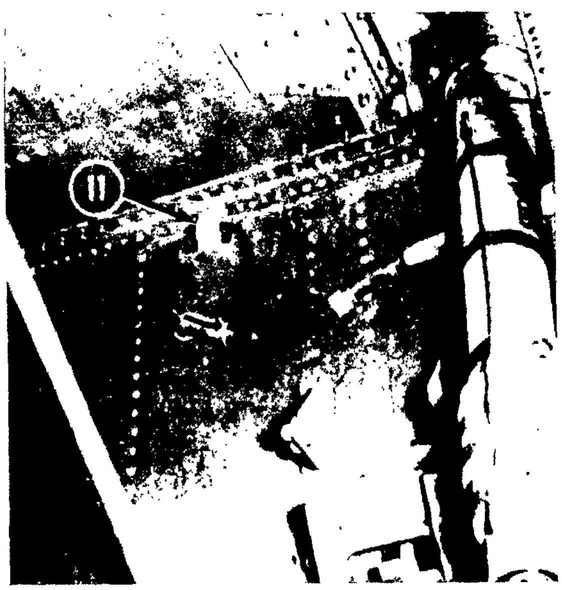


FIGURE 23c
Typical accelerometer installation. Accelerometer on forward wall of left main landing gear well, 11.

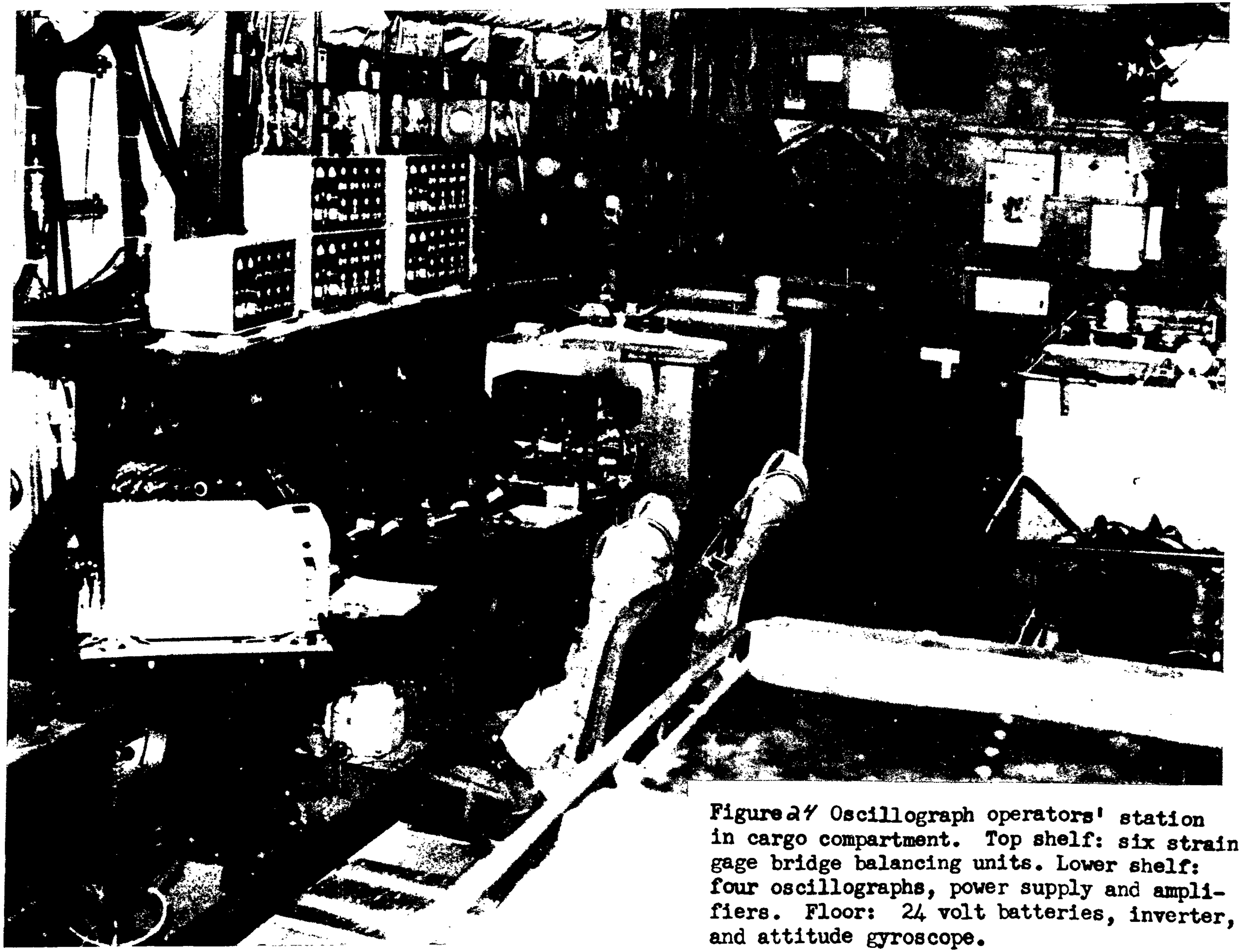


Figure 24 Oscillograph operators' station in cargo compartment. Top shelf: six strain gage bridge balancing units. Lower shelf: four oscillographs, power supply and amplifiers. Floor: 24 volt batteries, inverter, and attitude gyroscope.

Analysis for Forcing Function Time Histories from Oscillograph Records

The vertical force acting on the landing gear during the landing is not recorded as such on the oscillograph records. However, strain gages measured the axial forces on the oleo strut and main post. With the swivel arm position also being recorded, these two forces can be resolved into their vertical force of which they are the resultants.

In Figure 25 the components of the vertical forces along BC and OC respectively are $\overline{V} \cos \theta_{VCB}$ and $\overline{V} \cos (90° - \varphi)$

θ is assumed constant and $\varphi = \theta_{AOC} - (90° + \theta)$ where θ_{AOC} is the reading from the swivel arm position trace on the oscillograph records. Similarly, the drag force D_H is resolved into BC and OC as

$$D_H \sin \theta_{VCB} \quad \text{and} \quad - D_H \cos \varphi$$

Therefore the force registered on a strain gage along BC or the oleo axial load is

$$F_{V8} = \overline{V} \cos \theta_{VCB} \text{ and } D_H \sin \theta_{VCB} \tag{1}$$

The force along CO is

$$F_{CO} = \overline{V} \sin \varphi - D_H \cos \varphi \tag{2}$$

The force along CO is resolved into a force along AO as

$$F_{CO} = F_{V10} \cos (180 - \theta_{AOC}) \tag{3}$$

Solving Eq. (1) & (2) for $\overline{V}$ and D_H we find

$$\overline{V} = \frac{F_{V8} \cos \varphi + F_{CO} \sin \theta_{VCB}}{\cos (\varphi - \theta_{VCB})} \tag{4}$$

$$D_H = \frac{F_{CO} \cos \theta_{VCB} - F_{V8} \sin \varphi}{- \cos (\varphi - \theta_{VCB})} \tag{5}$$

where F_{CO} is given by Eq. (3).

F_{V8} and F_{V10} are the loads from the strain gage oscillograph recordings of the oleo axial load and the main post axial load.

To find θ_{VCB} consider the locus of the Point C, origin at O, as the oleo compresses, which describes the circle $X_C^2 + Z_C^2 = 1^2$. The coordinate of any point (X_C, Z_C) on the circle are

$$X_C = 1 \cos \varphi$$
$$Z_C = 1 \sin \varphi$$

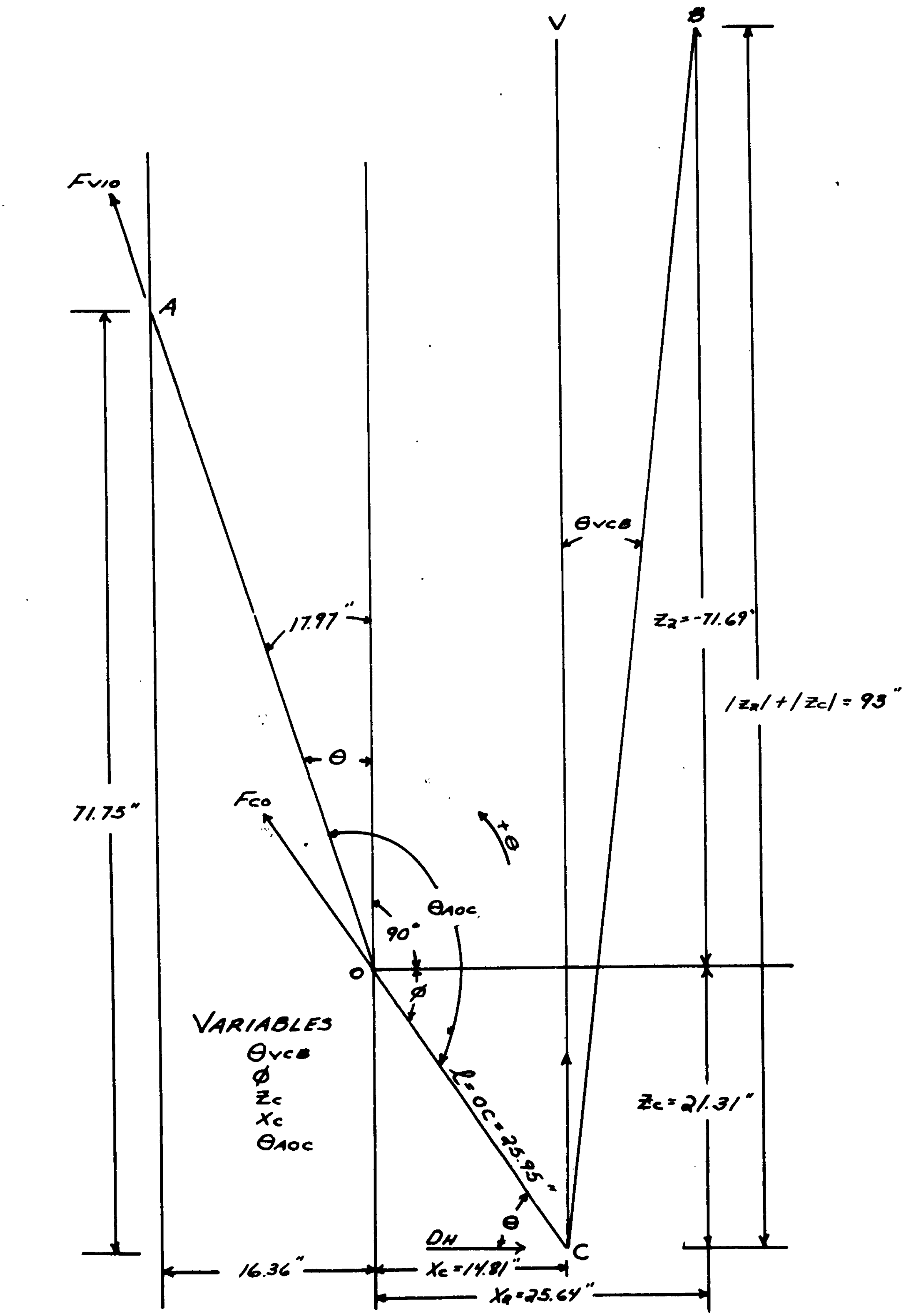


FIGURE 25 Schematic Diagram of Main Gear

and the slope of the line BC is

$$M = \frac{|Z_2| + |Z_C|}{X_2 - X_C}$$

Therefore

$$\theta_{VCB} = \tan^{-1} \frac{X_2 - X_C}{|Z_2| + |Z_C|}$$

Analysis of C-119-H Landing Records

An attempt has been made to make the C-119-H oscillograph records as nearly self explanatory as possible by incorporating most of the information necessary to read the records on the individual traces.

In photographing the oscillograph records there has been a necessary reduction in scale. The values recorded on the traces as trace sensitivity are on the basis of one inch of trace deflection before reproduction; and therefore, a reference scale has been drawn on each record to show the actual reduction in scale. This reduction must be taken into account on all readings.

All strain gage traces are at zero or no-load position at all times previous to initial touchdown. Therefore, any deflection from the zero position is a load which can be calculated by measuring the actual trace deflection and converting it to pounds by using the value for one inch deflection as recorded on the records. Reduction in scale must not be forgotten.

The accelerometer traces can be read directly from information available on the traces. A zero position of the trace can be established by fairing a line through the trace curve at a time previous to touchdown.

The rate of descent traces of left and right main gear, and the oleo position indicators can be read from information available on the traces.

Blips on Trace 14 represent 1/2 revolution of the left main gear wheel. This angular velocity can be converted to translation by finding the tire deflection from Trace 24 and subtracting this from the actual tire radius of 24.4". However, a reasonably accurate ground speed can be obtained by using a constant tire radius of 24 in. or 2 ft.

The time scale is in hundredths of a second with each tenth second line accented. For our purposes in reading the records t_o was arbitrarily chosen to be the instant the left main gear initially contacted the ground and is so marked.

No linear relationship exists between the applied force and the trace deflection for a number of the strain gages. This is true also for the angular position indicator. Therefore in the following table, formulae for approximations of loads and positions for varying trace deflections are given.

On Traces 4 through 7, it appears that when $d = 0$, a large positive force is still present. This is not true but indicates only that a certain force must be applied before a deflection is present.

Table 3 Computations and Sense of Traces - C-119-H

Trace	Computation		Pos. Trace Defl. Indicates
3 Aft Load	Load = (9800 x d + 1000) lbs. Load = 15,000 x d	$d \geq 0.2$ $d < .2$	Load front to Rear
4 Outb'd V Axle	Load = (23,360 x d + 3750) lbs.		Bending Up
5 Inb'd V Axle	Load = (19,610 d + 4300) lbs.		Bending Up
6 Outb'd D Axle	Load = (15,230 x d + 2200) lbs.		Load Front to Rear
7 Inb'd D Axle	Load = (24,380 x d + 2500) lbs.		Load Front to Rear
8 Yaw	$\psi^\circ = 12.5\ d$ $\psi^\circ = 12.5\ d$	$d < 0$ $d > 0$	Yaw to Left
12 L. Rudder Pos.	$\beta^\circ = 51.5 \times d$ $\beta^\circ = 57.1 \times d$	$d < 0$ $d > 0$	Rudder to Right
15 Aileron Pos.	$\beta^\circ = 20 \times d$ $\beta^\circ = 25 \times d$	$d > 0$ $d < 0$	Aileron Up
17 Elevator Pos.	$\beta^\circ = 33.3 \times d$ $\beta^\circ = 29.6 \times d$	$d > 0$ $d < 0$	Elevator Up
18 Elev. Spring Tab Pos.	$\beta^\circ = 20\ d$ $\beta^\circ = 20\ d$	$d < 0$ $d > 0$	Tab Up
19 Left M. G. Swivel Arm Pos.	$\theta_{AOC} = 165^\circ - 60 \times d$		Angle Decreasing
24 Nose R/D	$\bar{z}_3 = 12.5\ d$ $\bar{z}_3 = 21.7\ d - 3.7$	$d \leq 0.4$ $d > 0.4$	Plane Descending
26 Roll	$\phi = 12.5\ d$	$d < 0$ $d > 0$	Roll Left
27 Pitch	$\theta = 15\ d$	$d > 0$ $d < 0$	Nose Up

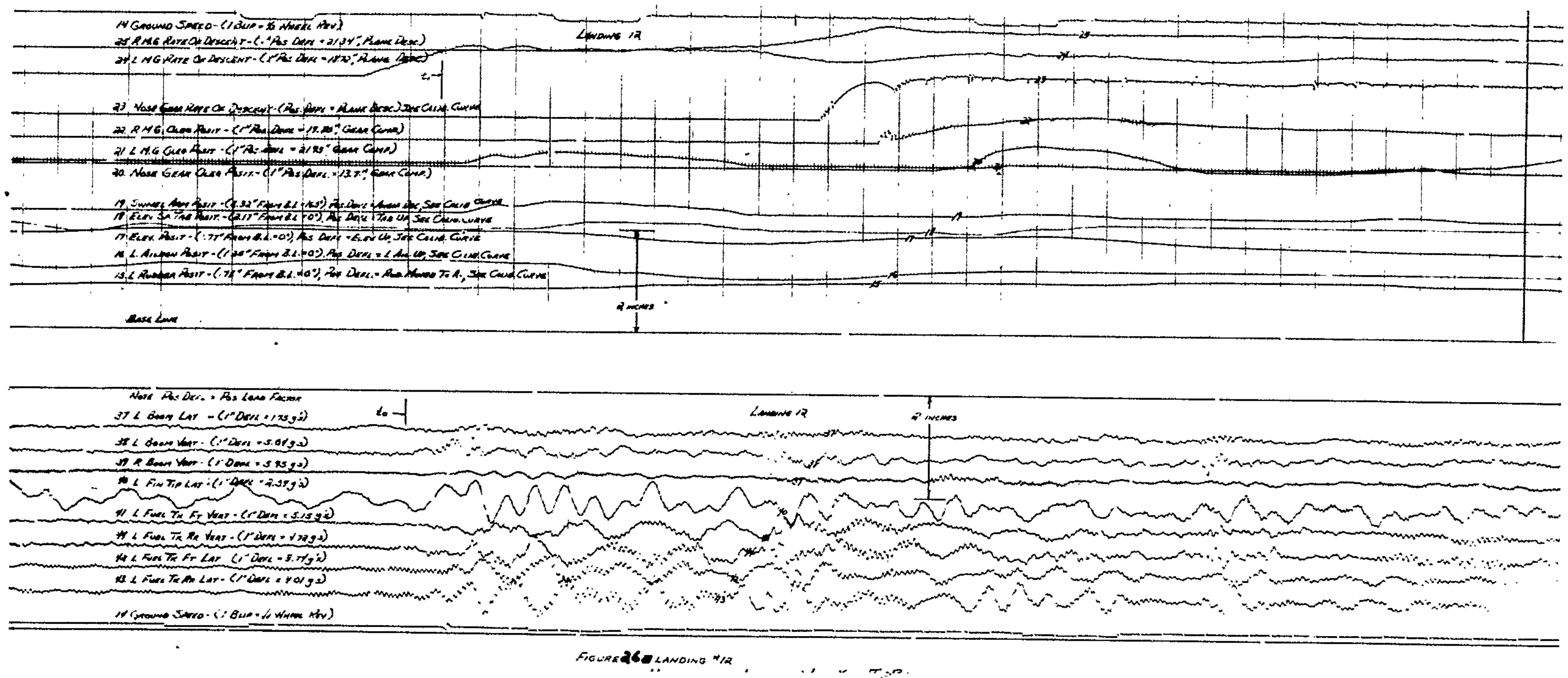


Figure 26a Landing #12 Unsymmetric Landing With Yaw To Right

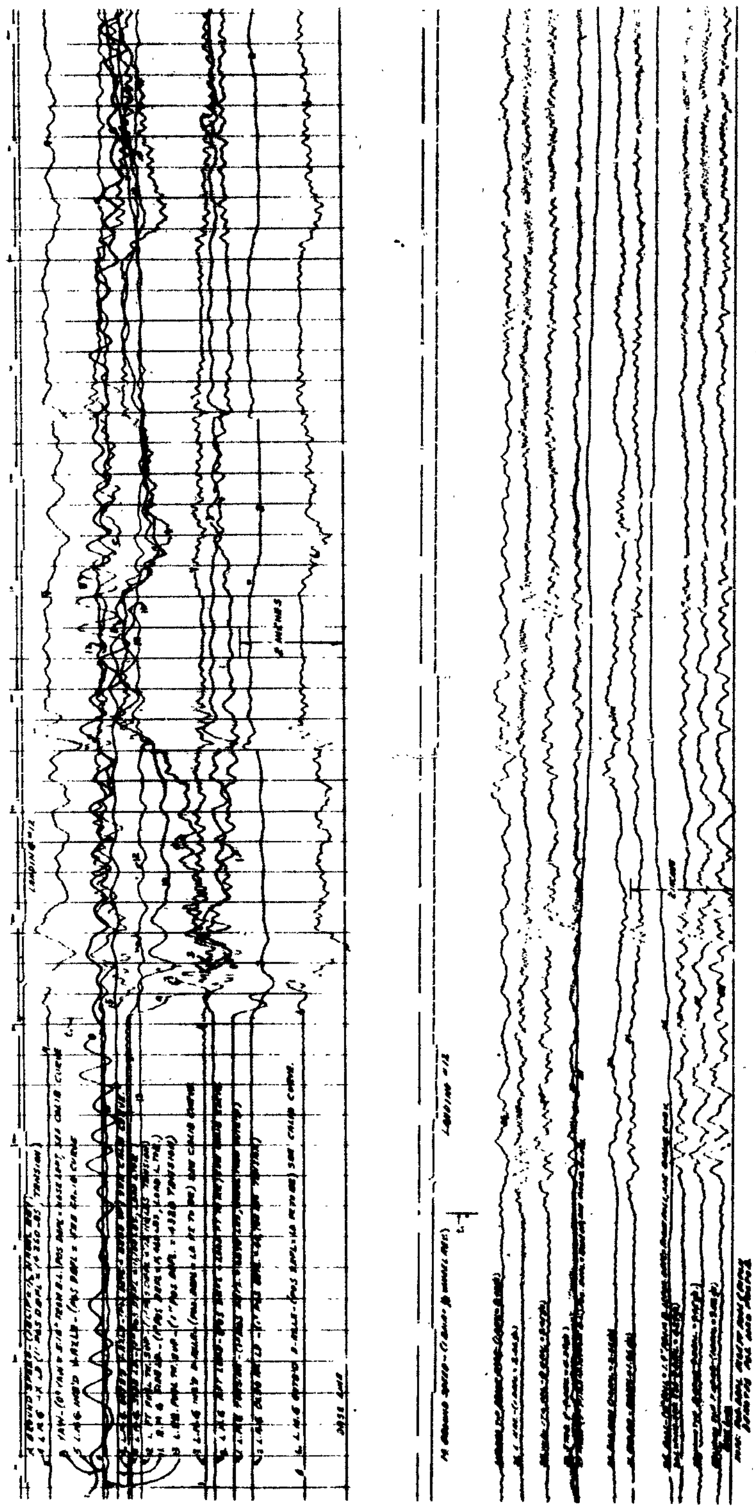


Figure 26b Landing #12 Unsymmetric Landing With Yaw To Right

Table 4 provides all necessary information for reading the F-84E landing records, on Figure 28 , Page 79.

Table 4 Computations and Sense of Traces F-84E

Weight 16,309
Tip Tanks Full

Trace No. and Designation	Computations	Sensitivity	Pos. Defl. Indicates
1. L.M.G. Vert. Load	S x d	S = 16,785 lbs.	Compression
2. L.M.G. Drag Load	S x d	S = 6,195 lbs.	Load Front to Rear
3. L.M.G. Side Load	S_1 x d - S_2 x V	S_1 = 4,019 lbs.	Inboard
L.M.G. Side Load		S_2 = 0.257	
4. R.M.G. Vert. Load	S x d	S = 12,600 lbs.	Compression
5. R.M.G. Drag Load	S x d	S = 6,650 lbs.	Load Front to Rear
6. R.M.G. Side Load	S_1 x d - S_2 x V	S_1 = 3,693 lbs.	Inboard
R.M.G. Side Load		S_2 = 0.273	
7. Nose Vert. Load	S x d	S = 2,826 lbs.	Tension
8. Nose Drag Load	S x d	S = 3,450 lbs.	Load Front to Rear
12. c.g. Accel.	d/S	S = 0.975 in./g	Neg. Accel.
13. Left Wing Rear Accel.	d/S	S = 0.205 in./g	Pos. Accel.
*14. Right Wing Rear Accel.	d/S	S = 0.1702 in./g	Pos. Accel.
15. Left Wing Fwd. Accel.	d/S	S = 0.2025 in./g	Pos. Accel.

*Because of large variations in size of calibration blip from flight to flight, the data of this channel is questionable.

In calculating the side load from Traces 3 and 6, assign sense of d as (+) or (-) and calculate the vertical force V of corresponding main gear at the same instant.

"d" is measured in inches of trace deflection for all traces.

Necessary data for analyzing the C-47 Flight Test Record on Figure 29 is provided on the following table.

Table 5 Computations and Sense of Traces - C-47

Trace No. and Designation	Computation	Sensitivity	Sense
1. L.M.G. Wheel Speed	$n \times S/\Delta t$, n = no. of blips in time Δt	97.5 in.	
2. L.M.G. R/D and Tire Defl.	$R/D = \Delta d\ S/\Delta t$ Tire Defl. = $d \times S$	21.85 in.	(+) Defl. = Airp. Desc.
5. L.M.G. Vert. Load	$d \times S$	14310 lbs.	(-) Defl. = Compression
6. L.M.G. Drag Load	$d \times S$	18240 lbs.	(-) Defl. = Load Front to Rear
7. L.M.G. Side Load	Rolling Radius = RR $= \lvert S_2 - 4.37\ d_{R/D} \rvert$ Load = $d\ S_1/RR$	S_1 = 102800 in.lb. S_2 = 16290 in.	(-) Defl. = Inb'd Load
8. c.g. Accel.	$d \times S$	7.15 g's	(+) Def. = Neg. Acc.
9. Pitch	$\theta = S_1\ (d - S_2)$ d = Distance from trace 14	$S_1 = 16.65°$ S_2 = 32.6 in.	(+) θ = Nose Down
10. Roll	$\varphi = S_1\ (d - S_2)$ d = Distance from trace 14	$S_1 = 14.10°$ S_2 = 35.5 in.	+ (ϕ) = Roll Left
11. R.M.G. Wheel Speed	Same as trace 1	97.5 in.	
12. R.M.G. R/D and Tire Defl.	Same as trace 2	20.4 in.	(+) Defl. = Airplane Desc.
13. R.M.G. Strut Defl.	$d \times S$	14.6 in.	(-) Defl. = Oleo Compress.
15. R.M.G. Vert. Load	$d \times S$	11800 lbs.	(-) Defl. = Tension
16. R.M.G. Drag Load	$d \times S$	15090 lbs.	(-) Defl. = Load Front to Rear
17. R.M.G. Side Load	Same as trace 7	S_1 = 142500 in.lbs.	Neg. Defl. Inboard Load
18. Tail Wheel Vert. Load	$d \times S$		

With the following exception "d" is the trace deflection in inches from the no load position. On trace 2, "d" for tire deflection is measured from the position of the trace at instant of tire contact. On traces 7 and 17, $d_{R/D}$ is the deflection of trace 2 or 12 at the instant the side load is to be read.

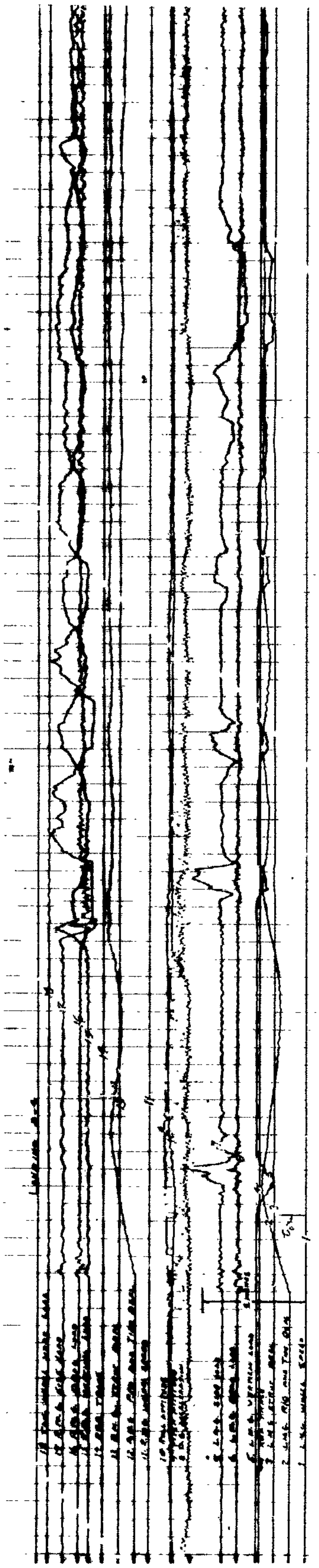


Figure 28 Typical Landing Record of F-24E

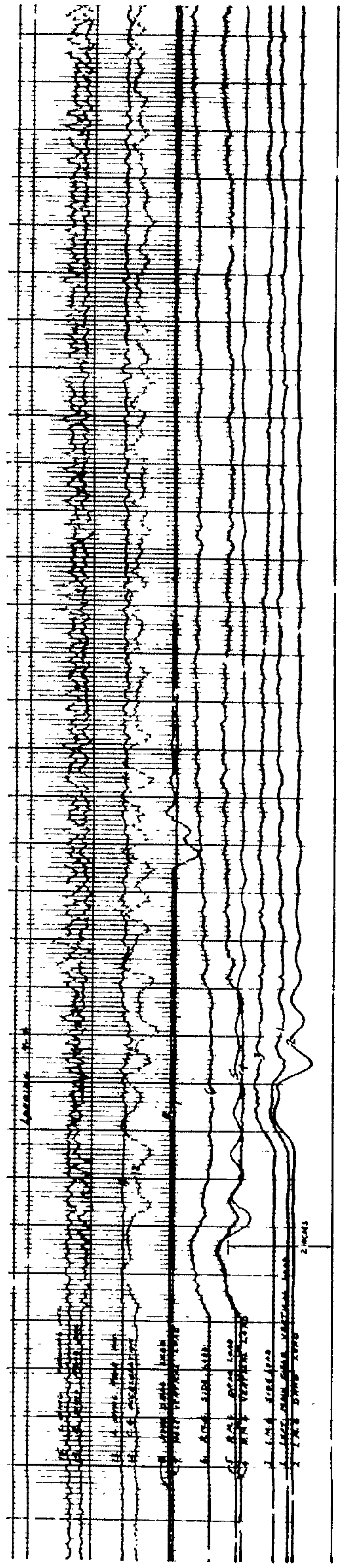


Figure 29 Typical Landing Record of C-47

Table 6 Computation and Sense of Traces - B-36

Record and Trace	Designation	Sensitivity (S)	Trace Defl. Indicates
I-1	Right Main Column Vertical Load	395,000 lbs.	Neg. Defl. = Load Upward
I-3	Right Main Column Side Load	41,400 lbs.	Neg. Defl. = Load Outboard
I-5	Right Oleo Strut	12.5 in.	Neg. Defl. = Compression
I-7	c.g. Accelerometer	8.44 g's	Pos. Defl. = Acc. Downward
I-9	Right Main Column Drag Load	53,600 lbs.	Neg. Defl. = Load Front to Rear
I-13	Right Fwd. Wheel Tachometer	25.7 rad./Sec.	
II-1	Left Main Column Vertical Load	365,500 lbs.	Neg. Defl. = Load Upward
II-2	Left Main Column Side Load	45,700 lbs.	Neg. Defl. = Load Outboard
II-5	Left Main Column Drag Load	55,500 lbs.	Neg. Defl. = Load Front to Rear
II-13	Rear Aft Wheel Tachometer	25.7 rad./Sec.	

Multiply sensitivity (S) by Deflection (d) of the trace from the pre-contact position of the trace.

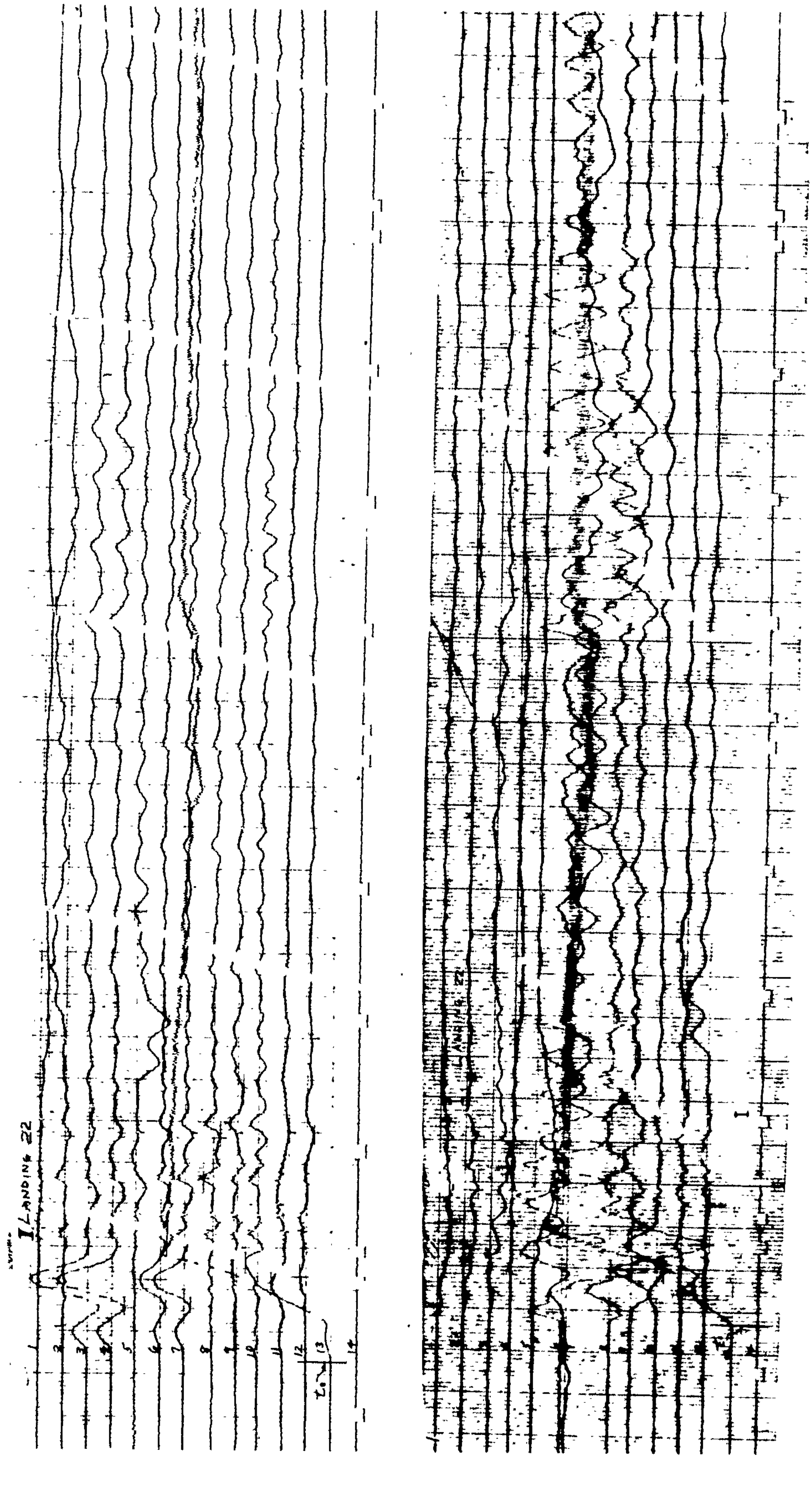


Figure 27 B-36 Landing 22

Summary of Test Results

A total of 42 landings were made varying the following conditions:

1. Rate of Descent
2. Symmetric Loading
3. Symmetric and Unsymmetric Landings
4. Roll
5. Pitch
6. Yaw
7. Stall
8. C. G. Location
9. Landing Speed

Only four of the landings were actually symmetric with the other landings having various intervals of time between contact of the first and second landing gears.

Complete rebound occurred in 25 of the 42 landings.

Stall landings were attempted, but full stall was not attained, and relatively low rates of descent were the only results of the attempts.

The ground landing speed was varied intentionally but would have varied anyway due to different loads and different wind velocities throughout the landings.

The range of all these parameter variances can be seen on Table 7.

The units of measurements and definitions of quantities in Table 7, are as follows:

1.	Weight	lbs
2.	C. G. Location	percentage MAC
3.	Wind Velocity - Wind Direction - Runway Direction	knot/degrees/degrees
4.	Fuel Loading	lbs x 10^{-3} left tip tank/right tip tank
5.	Ground speed - immediately following contact	ft/sec
6.	Roll - at instant of contact	degrees (L) or (R)
7.	Pitch - at instant of contact (Nose up always)	degrees
8.	Yaw - at instant of contact	degrees (L) or (R)
9.	Acc Fuselage c.g. - max acc and time at which it occurs	g's/sec
10.	Order of Gear Contacts	L = left, R = right, N = nose gear, L/R = both gears contact simultaneously, (N) omitted = no contact by nose gear

Left Main Gear:

11.	Time of contact, rebound & recontact	sec/sec/sec
	If only one time occurs there is no rebound	
12.	Rate of Descent - immediately previous to contact	ft/sec
13.	Oleo Position - max deflection and time it occurs	in/sec
14.	Torsion - max ld and time it occurs	lbs x 10^{-3}/sec
15.	Oleo Ax Ld - max ld and time it occurs	lbs x 10^{-3}/sec
16.	Aft Ld - max ld and time it occurs	lbs x 10^{-3}/sec
17.	Outb'd V Axle - max ld and time it occurs	lbs x 10^{-3}/sec
18.	Inb'd V Axle - max ld and time it occurs	lbs x 10^{-3}/sec
19.	Outb'd D Axle - max ld and time it occurs	lbs x 10^{-3}/sec

20.	Inb'd D Axle - max ld and time it occurs	lbs x 10^{-3}/sec
21.	Axial Ld - max ld and time it occurs	lbs x 10^{-3}/sec
22.	Side Ld Outb'd - max ld and time it occurs	lbs x 10^{-3}/sec
23.	Side Ld Inb'd - max ld and time it occurs	lbs x 10^{-3}/sec
24.	Swivel Arm Pos - max pos and time it occurs	degrees/sec
25.	Tire Deflection - immediately after initial contact with time for tire to deflect	in/sec

Right Main Gear:

26.	Time of Contact - rebound and recontact	sec/sec/sec
27.	Rate of Descent - immediately previous to contact	ft/sec
28.	Oleo Pos - max deflection and time it occurs	in/sec
29.	Side Ld Outb'd - max ld and time it occurs	lbs x 10^{-3}/sec
30.	Side Ld Inb'd - max ld and time it occurs	

Nose Gear:

31.	Time of Contact	sec
32.	Rate of Descent - immediately previous to contact	sec
33.	Oleo Pos - max deflect and time it occurs	in/sec
34.	Tire Pressure L & R Main Gear/Nose gear	PSI/PSI

Where a dash (—) occurs in a block no maximum was available as trace deflection was increasing to the end of the record.

The time scale is on the basis of t = o at the instant the left main gear contacts the ground.

Table 7 Maximum Values and Initial Conditions of C-119H Flight Test Records

	Landing Number	1	2	3	4	5
1.	Weight	66810	66710	66610	66510	66410
2.	C.G. Location	31.1	31.1	31.1	31.1	31.1
3.	Wind Vel-Dir-Runway	9/55/90	8/30/90	11/70/90	10/120/90	10/75/90
4.	Fuel Loading	3.0/3.05	2.95/3.0	2.9/2.95	2.85/2.9	2.8/2.85
5.	Ground Speed	114.9	117.8	116.3	110	117
6.	Roll	Not	Calibra	ted	0.68° L	2.0° L
7.	Pitch	9.1°	8.2°	6.4°	6°	4.8°
8.	Yaw	.72° L	.86° L	.43° L	0.86° R	0.86° R
9.	Acc. Fuselage C.G.	.55/.25	.46/.30	.69/.36	.27/.67	.38/.15
10.	Order of Gear Contacts	L-R	L/R	L-R-N	L-R-N	L-R-N
	Left Main Gear					
11.	Time Of Contact Reb'd. & Cont't.	0/.59/1.58	0/.85/1.16	0/.35/1.55	0	0/1.23/1.84
12.	Rate Of Descent	2.37	1.38	0.89	1.95	2.81
13.	Oleo Position	4.16/.35	5.4/2.80	-	7.07/.40	7.28/2.6
14.	Torsion	3.7/.20	-	3.2/.32	10.7/.71	7.85/.12
15.	Oleo Axial Load	15.2/.12	13.4/.15	10.3/.16	17.0/.11	15.6/.13
16.	Aft Load	4.5/.14	4.76/.3	3.85/.21	6.0/.11	5.0/.13
17.	Outb'd V Axle	16.5/.08	12.2/.18	11.0/.18	31.8/3.72	29.0/2.39
18.	Inb'd V Axle	31.7/.28	24.4/.31	15.3/.16	44.0/.67	30.8/.59
19.	Outb'd D Axle	10.3/.16	8.5/.20	6.0/.195	29.9/1.24	26.1/.13
20.	Inb'd D Axle	No	t C	ali	bra	ted
21.	Axial Load	17.9/.12	4.2/.3	2.24/.205	8.88/.72	6.36/.48
22.	Side Load Outb'd.	3.0/.65	1.1/.88	0.76/.75	4.0/3.74	3.78/2.23
23.	Side Load Inb'd.	9.7/.31	7.4/1.25	2.8/3.0	19.5/.35	15.0/.40
24.	Swivel Arm Position	152.5/.35	146.6/2.80	-	144/.40	143.5/2.60
25.	Tire Deflection	1.49/.05	1.12/.08	1.12/.15	1.69/.06	1.87/.05
	Right Main Gear					
26.	Time Of Cont't. Reb'd. Cont't.	.11/.62/1.58	0	.05/.83/1.15	1.0	0.8
27.	Rate Of Descent	2.30	1.67	1.11	0.70	1.49
28.	Oleo Position	2.30/.42	3.75/.31	1.46/.21	10.4/6.2	9.36/4.71
29.	Side Load, Outb'd.	6.92/.40	7.35/.33	1.23/.80	12.9/1.48	8.02/1.07
30.	Side Load, Inb'd.	2.2/6.5	1.1/8.05	1.89/.45	4.46/4.09	5.12/2.39
	Nose Gear					
31.	Time Of Cont't,	No	Contact	3.15	3.70	1.80
32.	Rate Of Descent	No	Contact	1.0	1.25	2.0
33.	Oleo Position	No	Contact	-	3.02/4.41	6.45/4.30
34.	Tire Pressure	70/40	70/40	70/40	70/40	70/40
35.	Complete Rebound	Yes	No	Yes	No	No

Table 7 Maximum Values and Initial Conditions of C-119H Flight Test Records (Cont'd)

	Landing Number	6	7	8	9	10
1.	Weight	66310	75100	74900	74700	74500
2.	C.G. Location	31.1	21.1	21.1	21.1	21.1
3.	Wind Vel-Dir-Runway	10/15/90	9/335/270	9/330/270	9/15/270	7/30/270
4.	Fuel Loading	2.75/2.8	3.0/3.1	2.9/3.0	2.8/2.9	2.7/2.8
5.	Ground Speed	121.7	143	148.5	148	143
6.	Roll	2.9°L	1.74°L	3.77°L	3.8°L	3.9°L
7.	Pitch	2.7°	3.52°	4.45°	4.5°	4.5°
8.	Yaw	0.43°R	0.86°L	1.84°L	0.74°L	1.35°R
9.	Acc. Fuselage C.G.	.29/.14	.51/.37	.64/1.14	0.39/.30	0.45/1.35
10.	Order of Gear Contacts	L-R-N	L-R-N	L-R-N	L-R-N	L-R-N
	Left Main Gear					
11.	Time of Contact Reb'd and Cont't.	0/1.41/1.81	0	0/1.03/1.54	0/1.14/1.52	0
12.	Rate of Descent	2.81	2.68	2.05	3.24	2.45
13.	Oleo Position	11.0/.72	17.3/6.7	11.8/5.50	7.02/.58	14.0/5.9
14.	Torsion	8.47/.09	6.95/.33	6.04/.21	7.78/.20	7.50/.26
15.	Oleo Axial Load	16.1/.13	18.4/.11	15.2/.11	14.3/.14	26.8/5.88
16.	Aft Load	4.8/.12	11.6/1.25	4.4/.14	4.4/.22	6.6/5.71
17.	Outb'd V-Axle	21.7/2.25	23.5/.09	23.8/.10	2.57/.14	21.0/.14
18.	Inb'd V-Axle	29.2/4.42	7.75/.26	32.3/1.79	32.5/1.64	31.8/1.0
19.	Outb'd H-Axle	16.4/.12	18.0/.22	15.4/1.52	9.6/1.12	6.0/.07
20.	Inb'd H-Axle	Not Cal.	14.0/.25	20.4/1.74	20.4/1.60	16.0/1.30
21.	Axial Load	4.38/.46	11.6/.33	11.8/.61	11.8/.27	15.2/.26
22.	Side Load Outb'd	3.67/2.27	0.56/.02	6.44/1.12	1.89/1.20	1.11/.08
23.	Side Load Inb'd	9.83/4.99	11.8/.34	11.4/1.64	10.98/1.66	13.9/.90
24.	Swivel Arm Position	131/.72	120/6.70	130/5.50	145/.58	118/5.90
25.	Tire Deflection	2.06/.05	1.90/.08	1.71/.09	2.27/.10	2.46/.10
	Right Main Gear					
26.	Time of Cont't. Reb'd. Cont't.	1.25	0.33	0.58	1.2/2.8/2.88	0.85
27.	Rate of Descent	0.79	3.39	2.50	2.41	2.14
28.	Oleo Position	8.94/2.38	14.1/6.69	7.88/5.55	9.1/1.83	12.3/5.9
29.	Side Load, Outb'd	11.7/4.70	7.79/.69	13.2/1.28	1.03/.40	12.6/1.34
30.	Side Load, Inb'd	4.3/2.70	1.03/.35	0.92/.58	9.96/1.60	1.15/.90
	Nose Gear					
31.	Time of Cont't	1.70	1.80	1.35	1.50	0.95
32.	Rate of Descent	1.92	0.88	1.29	2.58	1.21
33.	Oleo Position	5.76/2.26	8.61/6.60	6.32/5.19	5.27/3.37	9.68/4.92
34.	Tire Pressure	70/40	71/62	71/62	71/62	71/62
35.	Complete Rebound	No	No	No	No	No

Table 7 Maximum Values and Initial Conditions of C-119H Flight Test Records (Cont'd)

	Landing Number	11	12	13	14	15
1.	Weight	66[illegible]90	66480	66280	65020	64820
2.	C.G. Location	31.1	31.1	31.1	31.4	31.4
3.	Wind Vel-Dir-Runway	14/315/20	16/300/20	15/285/20	17/270/270	17/300/270
4.	Fuel Loading	3.0/3.0	2.9/2.9	2.8/2.8	2.9/1.4	2.8/1.3
5.	Ground Speed	122	118	121	114	113
6.	Roll	2.0°L	2.3°L	2.3°L	1.35°L	0.4°L
7.	Pitch	3.0°	3.3°	3.5°	3.6°	3.6°
8.	Yaw	1.47°L	4.0°R	2.0°R	3.9°L	4.5°L
9.	Acc. Fuselage C.G.	.59/.39	.35/.10	.41/.23	.36/.35	.36/-1.7
10.	Order of Gear Contacts	L-R-N	L-R-N	L-R-N	L-R-N	R-L-N
	Left Main Gear					
11.	Time of Contact Reb'd and Cont't	0/.83/1.83	0/.94/1.42	0/1.08/3.5	0/.93/1.56	0
12.	Rate of Descent	4.06	3.20	3.12	2.5	.63
13.	Oleo Position	9.43/.41	4.82/.32	8.77/.33	13.4/6.03	-
14.	Torsion	8.34/.10	9.71/.10	9.85/.15	7.2/.31	5.49/.33
15.	Oleo Axial Load	27.7/.11	19.2/.11	21.0/.13	17.3/.14	13.6/.33
16.	Aft Load	9.6/.11	7.0/.13	7.0/.15	6.1/.16	4.4/.23
17.	Outb'd V-Axle	64.7/.11	48.8/.13	60.5/.15	21.5/3.31	2.31/1.54
18.	Inb'd V-Axle	27.3/.13	23.8/3.66	23.5/3.66	39.8/.36	32.3/4.79
19.	Outb'd D-Axle	22.0/.14	27.1/.20	22.4/.18	20.2/.16	11.0/.24
20.	Inb'd D-Axle	21.4/.18	13.0/.14	18.9/.29	17.2/.90	12.3/.36
21.	Axial Load	12.5/.10	9.7/.90	8.4/.14	13.2/.31	5.03/.36
22.	Side Load Outb'd	16.0/.25	9.88/.17	13.2/.20	2.56/1.01	0
23.	Side Load Inb'd	4.55/1.08	3.66/3.79	2.0/.20	13.9/.31	7.37/3.98
24.	Swivel Arm Position	140/.41	152/.33	141/.33	128/6.03	-
25.	Tire Leflection	2.62/.06	2.25/.09	2.62/.07	1.90/.09	1.82/.14
	Right Main Gear					
26.	Time of Cont't. Reb'd. Cont't.	.32/.93/1.46	1.21	1.13	.25/.95/1.16	-1.9/-.94/.27
27.	Rate of Descent	3.29	2.58	2.05	2.30	2.84
28.	Oleo Position	8.71/2.07	11.1/1.85	10.9/1.90	10.1/6.18	7.27/-1.52
29.	Side Load, Outb'd	3.44/3.5	3.1/3.86	1.38/.55	9.97/.59	7.68/4.06
30.	Side Load, Inb'd	11.6/.51	11.1/1.52	4.8/1.52	1.15/.98	2.41/1.95
	Nose Gear					
31.	Time of Cont't.	1.61	1.35	1.45	1.70	1.45
32.	Rate of Descent	2.38	4.25	2.25	1.0	0.33
33.	Oleo Position	9.31/1.09	8.77/3.71	9.59/3.55	9.8/6.03	9.52/2.82
34.	Tire Pressure	65/40	65/40	65/40	61/40	61/40
35.	Complete Rebound	Yes	Yes	Yes	Yes	Yes

Table 7 Maximum Values and Initial Conditions of C-119H Flight Test Records (Cont'd)

	Landing Number	16	17	18	19	20
1.	Weight	64620	65755	65530	66940	66740
2.	C.G. Location	31.5	31.4	31.4	31.3	31.3
3.	Wind Vel-Dir-Runway	16/300/20	19/310/270	20/310/20	13/15/20	14/15/20
4.	Fuel Loading	2.7/1.2	4.03/1.02	3.9/0.9	3.1/3.1	3.0/3.0
5.	Ground Speed	120	122.6	119	111.5	109.2
6.	Roll	0.45°L	N.G.	1.45°L	2.4°L	0.1°L
7.	Pitch	5.8°	2.9°	3.0°	4.8°	3.6°
8.	Yaw	0.5°R	10.7°L	0.25°L	0.3°R	3.5°L
9.	Acc. Fuselage C.G.	.40/.21	.49/.08	.37/1.27	.40/1.37	.40/.32
10.	Order of Gear Contacts	L-R-N	R-L-N	L-R-N	L-R-N	L-R-N
	Left Main Gear					
11.	Time of Contact Reb'd and Cont't	0/.85/1.30	0/.73/1.35	0/.73/1.86	0/.78/1.9	0/.84/1.74
12.	Rate of Descent	2.68	3.08	1.77	1.15	1.58
13.	Oleo Position	7.07/.40	8.73/4.31	17.9/5.4	3.61/.38	4.70/2.31
14.	Torsion	12.7/.14	6.22/.17	6.42/.23	7.5/.17	8.48/.29
15.	Oleo Axial Load	17.3/.33	18.2/.14	12.2/.24	14.2/.17	16.9/.25
16.	Aft Load	6.0/.83	6.3/.70	7.9/5.44	5.6/1.7	5.8/.48
17.	Outb'd V-Axle	71.3/.34	22.0/.28	59.1/.32	33.8/.92	45.0/.33
18.	Inb'd V-Axle	20.2/3.87	24.5/.13	41.3/5.60	23.8/4.28	19.5/.33
19.	Outb'd D-Axle	36.0/.22	11.9/.70	26.8/.34	19.8/.26	19.5/.30
20.	Inb'd D-Axle	13.8/.16	15.0/.18	30.8/.31	11.4/1.9	14.5/3.26
21.	Axial Load	9.05/.68	10.3/.70	8.29/.70	5.79/1.95	6.43/0.25
22.	Side Load Outb'd	19.4/.19	2.20/.27	15.0/.57	5.95/.22	17.6/.38
23.	Side Load Inb'd	4.71/.90	2.4/1.56	8.6/5.50	2.46/3.85	7.48/2.94
24.	Swivel Arm Position	146.5/.41	141/4.3	116/5.4	153/.38	152/2.31
25.	Tire Deflection	2.84/.10	3.13/.08	1.70/.13	1.9/.13	1.97/.12
	Right Main Gear					
26.	Time of Cont't. Reb'd and Cont't.	1.33	-.39/.76/1.41	1.28/2.80/3.20	0.93	.23/.88/1.4
27.	Rate of Descent	2.84	2.61	2.97	1.88	1.33
28.	Oleo Position	10.7/2.10	9.7/.15	11.3/5.26	9.97/2.09	4.12/2.26
29.	Side Load, Outb'd	1.49/1.02	7.22/5.08	7.56/4.76	.92/.45	.19/3.06
30.	Side Load, Inb'd	13.5/1.66	3.90/.36	14.0/1.85	6.07/1.91	16.0/.65
	Nose Gear					
31.	Time of Cont't	1.65	1.45	1.50	1.8	1.66
32.	Rate of Descent	1.96	3.21	2.25	2.70	3.18
33.	Oleo Position	10.8/4.0	9.1/4.01	10.1/5.0	7.42/2.37	8.96/2.14
34.	Tire Pressure	61/40	65/40	65/40	65/40	65/40
35.	Complete Rebound	Yes	No	Yes	Yes	Yes

Table 7 Maximum Values and Initial Conditions of C-119 H Flight Test Records (Cont'd)

	Landing Number	21	22	23	24	25
1.	Weight	66540	66340	66240	66130	65940
2.	C. G. Location	31.3	31.3	31.3	31.4	31.4
3.	Wind Vel-Dir-Runway	14/15/20	11/15/20	12/0/20	13/15/20	9/0/20
4.	Fuel Loading	2.9/2.9	2.8/2.8	2.75/2.75	2.67/2.72	2.6/2.6
5.	Ground Speed	109.2	105.4	112	102	109
6.	Roll	0.5°R	1.4°L	1.2°R	N. G.	1.1°L
7.	Pitch	2°	6°	3°	8°	3.4°
8.	Yaw	0.4°R	0.1°L	1.75°R	2.4°L	1.3°R
9.	Acc. Fuselage C. G.	.22/.34	.30/.30	.36/.30	.20/.42	.38/.28
10.	Order of Gear Contact	R-L-N	L-R-N	R-L-N	L/R-N	R-L-N
	Left Main Gear					
11.	Time of Contact, Rebound & Contact	0	0/.66/1.5	0/.6/1.0	0/.59/1.64	0
12.	Rate of Descent	0.65	2.16	3.22	0.87	1.05
13.	Oleo Position	6.27/.65	10.3/6.7	2.01/.21	8.5/7.9	8.28/5.68
14.	Torsion	4.38/.28	6.4/.37	4.38/.29	4.86/.40	1.8/.19
15.	Oleo Axial Load	15.2/.27	16.0/.19	12.6/.22	12.1/.29	13.4/1.5
16.	Aft Load	5.9/.27	5.3/.19	3.9/.16	4.3/.31	5.2/.17
17.	Outb'd V Axle	26.3/.33	30.4/.19	20.0/1.24	29.5/1.91	23.6/2.33
18.	Inb'd V Axle	21.3/.35	21.5/1.57	20.3/.32	24.5/4.08	26.4/4.40
19.	Outb'd D Axle	11.8/1.25	15.2/.27	10.8/1.18	24.0/1.81	10.2/2.05
20.	Inb'd D Axle	10.4/.27	11.6/.19	13.6/.40	15.3/3.98	12.6/.28
21.	Axial Load	7.08/.26	6.44/.19	5.53/.16	9.52/.49	6.18/.29
22.	Side Load, Outb'd	4.1/1.71	4.3/.24	7.2/2.29	7.1/.45	2.56/2.2
23.	Side Load, Inb'd	.61/4.15	6.15/.83	3.07/.24	4.4/.41	3.07/3.91
24.	Swivel Arm Position	147/.65	130/6.7	159/.21	135/7.9	142/5.68
25.	Tire Deflection	1.9/0.8	1.9/0.9	1.7/0.12	1.9/.23	1.33/.09
	Right Main Gear					
26.	Time of Contact, Rebound & Contact	-1.22	1.04	-.21/.74/1.32	0/.57/1.84	-1.15/-.52/.05
27.	Rate of Descent	2.02	1.61	2.80	0.66	1.28
28.	Oleo Position	8.65/3.07	11.3/4.32	5.76/.16	10.9/7.77	9.89/5.78
29.	Side Load Outb'd	2.99/-.46	.69/.84	2.98/.16	2.52/3.92	2.41/-.9
30.	Side Load Inb'd	6.19/1.5	4.13/1.37	2.98/1.76	8.25/4.85	5.04/2.39
	Nose Gear					
31.	Time of Contact, Rebound & Contact	0.36	1.65	2.04	5.48	1.78
32.	Rate Descent	2.78	3.70	1.13	1.70	1.03
33.	Oleo Position	8.54/2.71	8.96/6.63	3.36/2.84	9.0/7.73	7.1/4.43
34.	Tire Pressure	65/40	65/40	65/40	65/40	65/40
35.	Complete Rebound	No	Yes	Yes	Yes	No

Table 7 Maximum Values and Initial Conditions of C-119H Flight Test Records

	Landing Number	26	27	28	29	30
1.	Weight	65890	65790	65590	65510	66960
2.	C.G. Location	31.4	31.4	31.4	31.4	31.3
3.	Wind Vel-Dir-Runway	13/0/20	9/345/20	9/345/20	10/15/20	4/155/20
4.	Fuel Loading	2.55/2.6	2.5/2.55	2.4/2.45	2.35/2.42	3.15/3.10
5.	Ground Speed	111	114	114	106	122
6.	Roll	N G	1.1°L	2.8°L	0.5°R	2.1°L
7.	Pitch	3°	3.2°	4.8°	6.5°	4.5°
8.	Yaw	2.8°L	2°L	3.6°R	0.3°L	0.4°R
9.	Acc. Fuselage C.G.	.44/.11	.32/.09	.38/.18	.44/.11	.38/.29
10.	Order Of Gear Contacts	L/R-N	L-R-N	L-R-N	R-L-N	L-R-N
	Left Main Gear					
11.	Time Of Contact Reb'd. & Cont't.	0/.53/1.47	0/.98/1.81	0/.65/2.11	0/.61/1.40	0/.86/1.92
12.	Rate Of Descent	4.04	2.26	3.03	2.82	1.88
13.	Oleo Position	5.6/2.03	7.16/.47	8.5/2.65	5.60/1.97	5.81/.35
14.	Torsion	6.6/.25	7.5/.17	9.38/.12	5.28/.30	5.53/.21
15.	Oleo Axial Load	13.4/1.73	16.5/.13	2/.2/.10	15.2/.16	14.8/.16
16.	Aft Load	4/.20	5.4/.17	6.0/.12	3.5/1.48	5.0/.83
17.	Outb'd V Axle	39.5/1.55	45.0/.18	38.3/.12	28.3/.35	31.1/.22
18.	Inb'd V Axle	30.1/2.70	27.3/2.62	31.8/2.45	24.3/1.89	24.8/4.52
19.	Outb'd D Axle	23.0/1.50	20.5/.21	15.6/.20	14.9/.56	12.0/2.0
20.	Inb'd D Axle	16.2/2.6	18.0/.26	22.0/2.19	14.6/.17	13.8/.30
21.	Axial Load	9.0/.34	7.98/.95	14.5/2.18	9.78/.45	8.29/.82
22.	Side Load Oubt'd.	15.5/1.55	13.4/.30	4.4/.17	7.58/.31	4.4/.26
23.	Side Load Inb'd.	8.6/3.09	6.86/2.75	4.82/2.39	2.66/.58	3.38/4.49
24.	Swivel Arm Position	149/2.03	147/.47	135/2.65	149/1.97	149/.35
25.	Tire Deflection	1.9/.12	2.08/.07	2.85/.07	1.9/.11	1.84/.10
	Right Main Gear					
26.	Time Of Cont't. Reb'd. Cont't.	0/1.02/1.58	0.57	2.37	.28/.63/1.68	0.58
27.	Rate Of Descent	3.47	1.82	2.71	2.54	2.07
28.	Oleo Position	5.15/.38	7.62/2.24	6.59/2.84	7.0/2.86	1.39/.79
29.	Side Load, Outb'd.	8.60/2.91	5.50/2.90	4.58/2.78	3.78/.65	3.32/4.39
30.	Side Load, Inb'd.	13.1/.37	7.91/.80	3.55/5.37	10.2/.05	3.32/2.15
	Nose Gear					
31.	Time Of Cont't.	1.78	1.57	3.27	2.73	2.17
32.	Rate Of Descent	4.38	0.88	1.06	1.06	2.36
33.	Oleo Position	8.12/2.51	9.1/2.17	8.12/4.14	2.38/3.12	8.64/4.54
34.	Tire Pressure	65/40	65/40	65/40	65/40	65/40
35.	Complete Rebound	Yes	No	Yes	Yes	No

Table 7 Maximum Values and Initial Conditions of C-119H Flight Test Records

	Landing Number	31	32	33	34	35
1.	Weight	66860	66710	66610	66510	66360
2.	C.G. Location	31.3	31.3	31.3	31.3	31.3
3.	Wind Vel-Dir-Runway	4/75/20	6/115/20	6/90/20	7/60/20	8/60/20
4.	Fuel Loading	3.10/3.05	3.0/3.0	2.95/2.95	2.9/2.9	2.82/2.83
5.	Ground Speed	127.5	133.6	142.0	12.10	123
6.	Roll	1.9°L	1.8°L	3.6°L	2.1°L	3.5°L
7.	Pitch	3.3°	2°	2°	8°	6°
8.	Yaw	1.2°R	2.4°R	2.3°R	3.8°R	3.1°R
9.	Acc. Fuselage C.G.	.40/.64	.40/.72	.51/.24	.40/.25	.32/1.26
10.	Order Of Gear Contacts	L-R-N	L-R-N	L-R-N	L-R-N	L-R-N
	Left Main Gear					
11.	Time Of Contact Reb'd. & Cont't.	0/1.08/1.90	0/1.2/2.06	0/1.17/2.23	0/1.13/1.63	0/.83/1.10
12.	Rate Of Descent	1.63	1.09	3.07	2.40	1.53
13.	Oleo Position	6.45/.7	6.02/.78	9.25/.36	8.39/.48	11.39/5.90
14.	Torsion	4.99/.32	4.56/.28	9.36/.16	7.38/.21	4.92/.23
15.	Oleo Axial Load	14.8/.18	13.4/.21	21.5/.14	17.9/.13	18.8/5.76
16.	Aft Load	5.3/1.07	4.6/2.8	7.1/.16	5.3/.17	3.4/.24
17.	Outb'd V Axle	29.8/.36	45.0/.36	52.1/.17	52.5/.27	36.9/.25
18.	Inb'd V Axle	25.5/5.90	21.[illegible]/5.51	24.8/3.03	25.0/3.55	27.5/3.44
19.	Outb'd D Axle	12.6/.32	17.4/.36	18.0/.20	21.2/.21	19.5/.33
20.	Inb'd D Axle	13.3/1.07	14.2/.44	17.7/.31	19.4/.28	9.4/2.48
21.	Axial Load	10.5/1.07	7.52/1.12	8.93/1.13	8.54/1.12	5.87/1.59
22.	Side Load Outb'd.	5.12/.29	9.22/.52	10.2/.21	12.1/31	8.29/.29
23.	Side Load Inb'd.	0.82/1.39	1.43/3.04	3.28/3.0	3.79/3.47	5.12/3.17
24.	Swivel Arm Position	145.5/.70	148/.78	140/.36	141/.48	130/5.90
25.	Tire Deflection	1.47/.08	2.21/.16	2.40/.07	2.40/.09	18/.16
	Right Main Gear					
26.	Time Of Cont't. Reb'd. Cont't.	0.59	0.65	0.80	0.59	1.19
27.	Rate Of Descent	2.12	1.92	1.97	2.67	1.53
28.	Oleo Position	4.36/1.10	3.37/.98	3.56/1.15	10.1/2.17	9.90/3.49
29.	Side Load, Outb'd.	0.80/3.86	0.69/0.52	1.83/3.2	3.21/3.45	3.9/3.41
30.	Side Load, Inb'd.	4.24/.78	7.79/1.05	4.58/1.25	11.0/.89	8.6/1.53
	Nose Gear					
31.	Time Of Cont't.	3.10	2.75	2.0	1.80	2.60
32.	Rate Of Descent	0.40	0.50	0.66	4.00	1.71
33.	Oleo Position	5.94/5.82	8.10/5.03	7.02/2.61	7.97/2.41	8.78/6.03
34.	Tire Pressure	65/40	65/40	65/40	65/40	65/40
35.	Complete Rebound	No	No	No	No	Yes

Table 7 Maximum Values and Initial Conditions of C-119H Flight Test Records

	Landing Number	36	37	38	39	40
1.	Weight	-	-	-	-	-
2.	C.G. Location	-	-	-	-	-
3.	Wind Vel-Dir-Runway	-	-	-	-	-
4.	Fuel Loading	-	-	-	-	-
5.	Ground Speed	110	110	117.4	105.5	97.4
6.	Roll	0.9°R	0.9°R	1.4°R	1.6°R	0.21°L
7.	Pitch	7.6°	3.5°	1.7°	7.1°	Not Cali.
8.	Yaw	0	1.0°R	0.3°R	0.3°R	0
9.	Acc. Fuselage C.G.	.29/1.56	.31/.45	.27/.35	.41/1.0	.46/.26
10.	Order Of Gear Contacts	R-L-N	R-L-N	L-R-N	R-L-N	L-R
	Left Main Gear					
11.	Time Of Contact Reb'd. & Cont't.	0/.7/.96	0/.78/1.84	0/.64/1.55	0/.88/1.13	0/.78/1.52
12.	Rate Of Descent	1.25	1.66	0.97	1.56	2.13
13.	Oleo Position	-	-	13.2/12.51	14.1/5.99	4.9/.33
14.	Torsion	2/79/.26	1.88/2.64	2.72/.29	3.91/.26	3.94/.16
15.	Oleo Axial Load	9.66/.13	11.96/2.64	5.52/.25	46.9/7.56	17.7/.12
16.	Aft Load	5.0/.33	3.7/.30	4.0/.25	4.2/.17	6.5/.17
17.	Outb'd V Axle	17.8/.33	18.5/1.94	16.1/.32	31.8/7.66	30.4/.24
18.	Inb'd V Axle	21.8/1.06	20.3/2.75	21.3/3.62	35.3/6.23	20.5/1.65
19.	Outb'd D Axle	7.6/.24	7.2/1.94	7.6/.28	29.1/7.53	12.1/.13
20.	Inb'd D Axle	NOT CALIBRATED				
21.	Axial Load	2.81/.33	1.71/.42	1.59/.34	1.83/.37	3.89/.21
22.	Side Load Outb'd.	.75/.74	2.35/.51	.86/.25	2.89/.32	2.92/4.28
23.	Side Load Inb'd.	4.6/1.07	3.0/2.89	3.82/2.70	5.56/6.39	4.64/.38
24.	Swivel Arm Position	-	-	124/12.51	122.5/5.99	151/.32
25.	Tire Deflection	1.1/0.1	1.5/.08	1.12/.09	1.87	1.64/.06
	Right Main Gear					
26.	Time Of Cont't. Reb'd. Cont't.	-.69/.18/1.04	-.08/.58/2.07	0.1/.73/1.32	-.47/.62/1.13	.05/.77/1.38
27.	Rate Of Descent	1.16	1.67	1.27	2.44	1.82
28.	Oleo Position	-	-	13.1/12.51	13.7/5.53	4.5/1.97
29.	Side Load, Outb'd.	4.67/1.17	1.82/.64	3.08/2.70	5.02/6.35	5.32/.28
30.	Side Load, Inb'd.	.57/.71	4.22/.22	1.25/.48	3.76/.21	4.45/5.28
	Nose Gear					
31.	Time Of Cont't.	5.80	2.60	2.90	2.60	No Cont.
32.	Rate Of Descent	0.5	0.8	0.33	1.57	No Cont.
33.	Oleo Position	9.04/7.06	4.11/6.64	9.86/12.51	10.0/6.86	No Cont.
34.	Tire Pressure					
35.	Complete Rebound	Yes	Yes	Yes	Yes	Yes

Table 7 Maximum Values and Initial Conditions of C-119H Flight Test Records

	Landing Number	41	42
1.	Weight	-	-
2.	C.G. Location	-	-
3.	Wind Vel-Dir-Runway	-	-
4.	Fuel Loading	-	-
5.	Ground Speed	100.1	104.7
6.	Roll	0°	0.21°L
7.	Pitch	N O T C A L I	B R A T E D
8.	Yaw	0	0.12°L
9.	Acc. Fuselage C.G.	.35/.17	.44/.42
10.	Order Of Gear Contacts	R/L	L-R-N
	Left Main Gear		
11.	Time Of Contact Reb'd. & Cont't.	0/.7/1.36	0/.76/1.62
12.	Rate Of Descent	1.07	1.68
13.	Oleo Position	4.73/5.59	-
14.	Torsion	4.22/.31	6.22/.11
15.	Oleo Axial Load	13.6/5.60	41.4/8.9
16.	Aft Load	4.6/.20	5.7/.15
17.	Outb'd V Axle	20.1/4.84	26.9/3.69
18.	Inb'd V Axle	26.2/1.58	30.6/3.70
19.	Outb'd D Axle	7.0/.19	24.0/7.73
20.	Inb'd D Axle	N O T C A L I	B R A T E D
21.	Axial Load	4.96/.32	2.60/.26
22.	Side Load Outb'd.	2.59/4.30	2.38/1.86
23.	Side Load Inb'd.	8.96/.32	2.16/3.13
24.	Swivel Arm Position	152/5.59	-
25.	Tire Deflection	1.83/.14	2.38/.10
	Right Main Gear		
26.	Time Of Cont't. Reb'd. Cont't.	0/.66/1.42	.14/.92/1.51
27.	Rate Of Descent	1.47	2.17
28.	Oleo Position	5.7/5.79	-
29.	Side Load, Outb'd.	6.08/.40	1.19/3.40
30.	Side Load, Inb'd.	3.69/4.56	4.13/1.51
	Nose Gear		
31.	Time Of Cont't.	No Contact	3.18
32.	Rate Of Descent	No Contact	0.97
33.	Oleo Position	No Contact	-
34.	Tire Pressure	-	-
35.	Complete Rebound	Yes	Yes

Table 8 **Maximum Values and Initial Conditions of F-84 E Flight Test Records**

Landing	4-5	4-6	5-5	6-1	7-4	8-1
1. Weight	13239	12959	14814	15974	16309	17269
2. Tip Tank Loading	Empty	Empty	½ Full	½ Full	Full	Full
3. Order of Gear Contact	L-R-N	R-L-N	R-L-N	L-R-N	R-L-N	L-R-N
4. C.G. Acceleration	.38/.1	.44/.98	.34/.265	.30/1.64	.35/.40	.58/.13
Left Main Gear						
5. Vertical Load	4.82/.1	5.46/.22	5.42/.26	5.36/2.04	5.71/.43	5.64/.11
6. Drag Load	1.82/.1	2.42/.23	3.08/.54	1.31/.14	2.23/.42	3.10/.11
7. Side Load	1.01/2.02	.38/2.95	.64/.26	.35/2.04	.31/.49	.66/.12
Right Main Gear						
8. Vertical Load	3.15/1.56	3.80/.54	4.54/.13	5.75/1.81	5.54/.14	5.65/.31
9. Drag Load	1.30/.83	2.60/.54	2.69/.12	2.38/.79	2.66/.14	2.99/.29
10. Side Load	.56/3.52	1.55/.56	.61/2.78	.34/.81	.26/.14	.33/.32
Nose Gear						
11. Vertical Load	1.51/3.19	.86/3.13	1.32/1.11	2.21/1.75	-	2.18/.79
12. Drag Load	1.35/1.89	1.08/2.33	1.40/1.01	1.76/1.59	1.65/.97	1.78/.70

Unit of Table

All loads are in lbs. x 10^{-3}, the weight is in lbs. and the c.g. acceleration is measured in "g's". The loads and accelerations are maximum values and are accompanied by the time at which they occur.

Table 9 Table of Maximum Values from B-36 Flight Test Records

Landing	11	18	22	23	26	29
Left Main Gear						
1. Main Col Vert Load	65.8/.37	65.8/.56	58.5/.76	51.2/.53	65.8/.46	102.3/.11
2. Main Col Side Ld Outb'd	10.9/.44	5.59/.54	5.48/.52	5.48/.42	3.65/.41	4.11/.07
3. Main Col Side Ld Inb'd	3.66/.29	5.48/.69	16.4/1.78	9.14/1.35	10.0/.46	40.2/.22
4. Main Col Drag Ld	37.7/.40	33.3/.54	37.7/.8	55.5/.52	18.9/.34	.012/.21
Right Main Gear						
5. Main Col Vert Ld	94.8/.17	110/.36	102/.23	110.6/.24	126.4/.32	205.4/.11
6. Main Col Side Ld Outb'd	2.48/.05	6.62/.22	18.2/.36	13.2/2.2	7.45/.19	30.6/.24
7. Main Col Side Ld Inb'd	18.2/.18	9.11/.48	5.80/1.43	9.11/.25	5.80/.25	2.07/.56
8. Main Col Drag Ld	34.3/.21	20.4/.39	23.5/.12	19.3/.14	23.6/.14	73.9/.14
9. Oleo Strut Stroke	8.0/.41	5.0/.42	4.0/.31	6.0/.39	7.0/.45	14.0/:28
10. Right Aft Wheel Tachometer	119	196	181	177	200	157
11. Right Fwd Wheel Tachometer	130	208	196	192	253	181
12. Order of Contact	R-L	R-L	R-L	R-L	R-L	L-R

Unit for Table 9, B-36

All loads are in lbs x 10^{-3} with the time of the occurrence of that load recorded in seconds. Ground speed from the wheel tachometer is read in feet per second.

Units for Table 10, C-47

1.	Weight	lbs
2.	C. G. Acc	g's
3.	Wind Velocity - Wind Direction - Runway Direction	MPH/degrees/degrees
4 - 6.	Yaw, Pitch, Roll	degrees/sec
7, 17.	Rate descent	ft per sec
8, 18.	Rolling Radius	inches/sec
9, 19.	Ground Speed	MPH
10, 20.	Oleo Deflection	inches/sec
11, 21.	Tire Deflection	inches/sec
12 - 16, 22 - 31,	All Loads	lbs x 10 $^{-3}$/sec

Table 10 Table of Maximum Values and Initial Conditions for DC-3 Landing Test Records

Flight and Landing Number	2-4	5-3	6-3	6-8	8-2
1. Landing Weight	23185	24785	24585	24585	24585
2. C. G. Acceleration	.33/.65	.37/.43	.30/.7[illegible]	.45/.87	.37/.55
3. Wind Vel.-Dir. Runw'y	10/0/270	10.2/110/340	15/215/270	5.75/160/270	7/30/270
4. Yaw Angle	9L	8L	7L	4L	9L
5. Pitch Angle	1.5U/.45	4.2U/.44	4.3U/.48	4.8U/.51	3.3U/.32
6. Roll Angle	.65R/.45	3.0L/.44	1.9L/.48	.42L/.51	3.10L/.322
Left Gear					
7. Rate of Descent	1.8	3.75	1.9	1.8	2.63
8. Rolling Radius	20.7/.60	19.4/.40	19.2/.65	20.2/.65	19.7/.50
9. Ground Speed	90.4	95.5	91.7	89.1	87.9
10. Oleo Deflection	- - -	- - -	- - -	- - -	- - -
11. Tire Deflection	1.54/.60	3.39/.40	3.32/.65	2.32/.65	2.91/.50
12. Vertical Load	4.8/.64	10.7/.38	16.0/.62	9.4/.66	10.4/.47
13. Drag Load	3.7/.70	6.5/.43	5.1/.63	5.2/.71	4.6/.52
14. Forward Load	1.2/.63	5.2/.40	4.0/.65	3.9/.68	5.6/.49
15. Inboard Side Load	1.2/.78	1.3/.74	.41/.58	.50/.94	.13/.36
16. Outboard Side Load	3.6/.71	5.8/.43	8.3/.68	3.9/.76	8.0/.52

Table 10 Table of Maximum Values and Initial Conditions for DC-3 Landing Test Records (cont'd)

Flight and Landing Number	2-4	5-3	6-3	6-8	8-2
Right Gear					
17. Rate of Descent	0.93	1.65	1.95	1.80	2.38
18. Rolling Radius	21.3/2.05	21.6/.83	20.4/.82	21.3/.84	20.3/.75
19. Ground Speed	88.9	97.0	89.1	90.2	84.0
20. Oleo Deflection	.26/3.25	.93/4.03	.15/2.12	.32/2.10	.15/.80
21. Tire Deflection	1.62/2.05	1.37/.83	2.26/.82	1.36/.84	2.18/.75
22. Vertical Load	8.1/2.07	3.6/.92	11.9/.86	6.9/.89	10.3/.78
23. Drag Load	5.1/2.12	2.1/.93	7.2/.91	3.7/.85	6.6/.82
24. Forward Load	2.9/2.09	2.1/1.04	.92/.87	1.9/.87	4.6/.79
25. Inboard Side Load	4.1/2.10	3.5/.95	8.2/.91	6.9/.92	9.3/.83
26. Outboard Side Load	.56/2.00	1.4/1.02	.65/1.18	.74/1.14	.96/1.11
27. Tail Wheel Vert. Load	- - -	1.3/30.84	2.3/28.13	1.9/19.80	1.7/20.90
Post Impact Side Loads					
28. Left Max. Inboard	2.3/5.55	3.5/7.89	2.9/6.99	1.2/1.86	3.3/4.38
29. Left Max. Outboard	- - -	- - -	- - -	- - -	- - -
30. Right Max. Inboard	- - -	5.8/1.97	- - -	- - -	- - -
31. Right Max. Outboard	1.6/3.60	2.9/9.09	2.2/3.76	1.5/2.86	3.2/4.65

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